SYSTEM EVALUATION BY THE SIMPLIFIED PROPORTIONAL ASSIGNMENT TECHNIQUE

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by

HASSAN AYAD

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Progress Report

SYSTEM EVALUATION BY THE
SIMPLIFIED PROPORTIONAL ASSIGNMENT TECHNIQUE

TO: G. A. Leonards, Director
Joint Highway Research Project

June 20, 1967

File: 3-7-3

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-69C

The attached Progress Report entitled "System Evaluation by the Simplified Proportional Assignment Technique" has been prepared by Mr. Hassan Ayad, Graduate Instructor in Research on our staff. This investigation is part of the "Urban Transportation Planning Process" research project. Mr. Ayad also used this research report as his thesis in his graduate program for the degree of Doctor of Philosophy. Professor J. C. Oppenlander provided guidance for this research in transportation planning.

The purpose of this study was to develop a rational concept for the evaluation of urban transportation systems. A proposed plan is considered adequate when the transportation facilities accommodate to a reasonable degree the traffic movements at the specified service levels. A desire assignment procedure is employed to determine the nature, magnitude and location of deficiencies on a transportation system. Link and zonal deficiencies define the nature and the extent of the improvements needed to make a plan adequate.

This Progress Report is presented to the Board for the record, and copies will be forwarded to the Bureau of Public Roads and the Indiana State Highway Commission for their review and comments.

Respectfully submitted,

Harold L. Michael
Associate Director

HLM:ss

Attachment

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Progress Report

SYSTEM EVALUATION BY THE SIMPLIFIED PROPORTIONAL ASSIGNMENT TECHNIQUE

by
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Joint Highway Research Project

Project: 3-7-3

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Conducted by

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and the

U.S. Department of Transportation
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ABSTRACT

Ayad, Hassan. Ph. D. Purdue University. June 1967. System Evaluation by the Simplified Proportional Assignment Technique. Major Professor: Joseph C. Oppenlander.

Traffic assignment is the process of allocating trip interchanges to a transportation system. This operation is performed to reproduce both present and future traffic flow patterns, evaluate proposed plans or optimize network flows. Most existing assignment procedures are designed either to reproduce flow patterns or to optimize network operation. Although the major use of traffic assignment in urban transportation studies is to evaluate proposed plans, no analytical procedure has been available to quantify the adequacy of a transportation system.

The purpose of this study was to develop a rational concept for the evaluation of urban transportation systems. The concept is based on the premise that the adequacy of a plan is described as the degree to which its design features satisfy the study objectives. From the standpoint of transportation, these objectives are defined as the attainment of selected levels of service between pairs of urban zones. A plan is considered adequate when the transportation facilities accommodate to a reasonable degree the traffic movements at these desired service levels.

A desire assignment procedure is employed to determine the nature, magnitude and location of deficiencies on a transportation system. Trip interchanges are assigned on a proportional basis only to acceptable routes that satisfy the pre-set levels of service. The assignment technique results in the detection of link and zonal deficiencies. Link deficiencies occur when the loads on street segments exceed the ability of these sections to provide a desired quality of traffic flow. If no acceptable route exists between a zonal pair, a zonal deficiency results, and trip interchanges can be accommodated only by improvements on the system. Link and zonal deficiencies define the nature and the extent of the improvements needed to make a plan adequate.

The new concept for the evaluation of transportation systems is identified as the Simplified Proportional Assignment Technique, or SPAT. The various components of this technique were formulated, and the associated parameters were quantified in this research investigation. A computer program was prepared to develop this technique into an operational format. The application of the process to transportation networks was demonstrated and analyzed for two cities differing in size and characteristics.

The Simplified Proportional Assignment Technique is a reliable and practical method for the evaluation of transportation plans. This new concept features a pioneering attempt to quantify the adequacies and deficiencies of transportation systems in relation to established study objectives.

INTRODUCTION

The allocation of travel movements to a transportation system is known as traffic assignment. The interchanges between selected origins and destinations can be person or vehicular trips for a single or several modes of travel. The assignment of trips assists in the evaluation of traffic operational measures for a transportation system and also permits the study of traffic usage of proposed facilities during the planning process.

The assignment of trip interchanges to a transportation system is performed for the following purposes:

1. Reproduction of travel patterns.
2. Evaluation of proposed plans.
3. Optimization of network flows.

In the reproduction of travel patterns, trips are allocated to the transportation system so that the assigned volumes are similar to the actual volumes accommodated on the links of the network under the existing or projected conditions. The procedure may involve the allocation of the existing or a projected set of trip interchanges to the existing or a proposed system. The process is employed to study the changes in flow patterns produced by either a change in the operational controls or by the addition of new facilities to a system. Examples of various traffic controls which may be evaluated include parking restrictions, one-way street operation and special treatment of major intersections. The new facilities, whose influence on the operation of the system may be considered, include the construction of expressways and interchanges and the widening of existing street sections.

Traffic assignment is also used to evaluate proposed plans and to detect deficiencies in transportation systems. When the technique is used for this purpose, trips are allocated only to desire routes. Between an origin and a destination, one or more desired routes may exist for the assignment of trip interchanges. Projected travel movements are allocated to either existing or proposed plans. The comparison of assigned volumes with available capacities is a measure of the possible deficiencies existing on the various sections of the system for the design period under consideration.

A third application of traffic assignment is the determination of the optimum usage of a transportation network. Trip interchanges are allocated to the network to optimize one or more chosen travel parameters, such as the total cost of travel or the total time spent by drivers on the network. From this assignment, appropriate traffic engineering control measures are selected to regulate the movement of traffic on the real system in accordance with the conditions producing optimum flow. Example control techniques include one-way street operation, parking restrictions, use of reversible lanes and metering or closure of selected ramps on expressways.

During the past few years, work in the area of traffic assignment has been concerned primarily with the reproduction of travel patterns. The approaches have advanced from trip assignments based purely on personal judgment to systematic computerized procedures. The formulation of traffic assignment techniques to evaluate proposed plans has received little attention. Present procedures are not conceptually sound and are in need of further formulation. The optimization of traffic operation on a given system is a relatively recent endeavor and success has been limited to the treatment of only system segments.

Assignment techniques differ in the choice of the routes to which trips are assigned and in the treatment of capacities of the links that make up these routes. When all trips are assigned to the "best" route only, the process is known as "all or nothing" assignment. The use of more than one route for the allocation of trips is called "proportional" assignment. A special case of the latter is the consideration of two routes of differing nature, namely an expressway and a major arterial. An allocation of this type is often accomplished by the application of "diversion" curves. Any number of routes may be used for any of the three purposes of assignment.

The treatment of link capacities is a function of the purpose of the assignment. In the evaluation of transportation systems for the determination of possible deficiencies, a desire assignment is sought, and the link capacities are not taken into consideration in the assignment technique. The links are allowed to carry traffic volumes in excess of their capacities to show travel desires. In simulation assignments, including optimal ones designed for system operational improvement, the load-carrying abilities of the links are included as a practical constraint. This technique is called "capacity-restraint" assignment and is designed to reflect the volume-delay interaction experienced on real networks. The travel delays are considered by adjusting the impedance factors on the links in accordance with the assigned traffic loads. The adjustments are iterative in nature and may be applied after all or portions of the trip interchanges are assigned to the respective route sections.

The use of traffic assignment in metropolitan area transportation studies has centered on the determination of expected loads on the various parts of proposed systems of transportation. The present approach is to devise a capacity-restraint model to describe the expected usage of a system. The accuracy of the assignment model is verified by assigning present trip interchanges to an existing network and by comparing the obtained volumes with field counts. The model is then employed to develop the expected flow patterns on alternate plans.

The major problem associated with the attainment of the "best" transportation plan for a community stems from the present approaches to the development of these plans. There are no exact methods at the present time for testing the adequacy of a transportation system in carrying a given set of trip interchanges or in meeting the study objectives. Plans are developed on the basis of rough methods of estimation like the "all or nothing" non-capacitated assignment. In addition, the capacity-restraint models do not reflect travel desires or point to system deficiencies. Their application to a developed plan does not insure that the plan adequately meets the study objectives. It is possible to accept badly planned networks with balanced volumes on them by using capacity restraint models.

The purpose of this research investigation was to develop a rational concept for the evaluation of transportation systems. The concept was designed to permit the analysis of any transportation system by quantifying the degree to which its facilities satisfy the study objectives and the travel desires of the community. This new concept is identified as the Simplified Proportional Assignment Technique or simply SPAT. It was based on the premise that the community objectives as related to transportation are the attainment of particular levels of service between origin-destination combinations within the study area. These levels of service may differ from one community to another and may vary over the years for the same community. Proper service levels are selected to reflect the desires of the people for a transportation system which must be restricted by financial and technological limitations.

The establishment of the levels of service desirable of a selected system for a particular stage in the community growth pattern determines the framework within which an acceptable plan is to be developed. Only those plans that meet these levels of service are considered in the decision-making process. The adequacy of an existing system in meeting the desired levels of service is first investigated. For every origin-destination combination, all routes providing movement between the terminals of a trip at pre-set service levels are determined. Trip interchanges are then assigned to these routes on a proportional basis in accordance with their relative attractiveness for the particular travel interchanges. The plan used in the assignment technique may include either an existing or a proposed system of transportation.

The application of the above assignment model may result in one or more of three possible outcomes. First, no route may exist between an origin and a destination that can accommodate traffic at the desired level of service. This situation is defined as a zonal deficiency, and system improvements must be planned for these unassigned travel interchanges. Secondly, some links may be assigned more traffic than they are able to carry at the desired levels of service. In this case, improvements are needed on or in the vicinity of these links to carry the excess traffic. Thirdly, the existing or proposed system may be able to carry the assigned volumes and provide the desired levels of service with no deficiencies.

Development of a computer program for the application of the Simplified Proportional Assignment Technique was included in this investigation. The program was applied to two cities to quantify some of the variables of the concept and to demonstrate the use of the technique in urban transportation studies.

The Simplified Proportional Assignment Technique is a practical and reliable method of system evaluation. It eliminates some of the major problems associated with the present approaches to the development of transportation plans by encompassing the following features.

1. The model provides for a direct and simple way of plan evaluation by considering the differences in goals and resource limitations within and among different communities. The new technique

accounts for priorities in budgetary expenditures of a city. The relative standing of transportation among other community needs is reflected in the choice of the appropriate levels of service.

2. SPAT is a non-iterative assignment technique. The allocation of trip interchanges to the respective routes in a single step is in line with the drivers' predetermined choice of a corridor of travel. The proportional assignment employed is a realistic representation of drivers' use of more than one available route between an origin and a destination.

3. The technique enables the quantitative determination of the possible deficiencies on a system. The nature and the degree of the needed improvements are readily obtainable.

4. This procedure permits the correlation of selected service levels with the economics of providing these qualities of traffic flow in the urban community.

5. The Simplified Proportional Assignment Technique allows for complete flexibility in the function of a developed plan. Preferential improvements to favor particular trip purposes can be exercised by the proper choice of the levels of service.

REVIEW OF LITERATURE

The transportation planning studies performed in recent years have been concerned with determining the amounts of traffic that will use different sections of a proposed plan. Such knowledge is imperative in testing the adequacy of plans proposed for selected design years. Work on this subject has progressed from the consideration of traffic to be used by a single facility like a bypass or an expressway to the development of traffic flow patterns over a whole network. The techniques have ranged from procedures based on judgment to systematic computerized processes.

Extensive efforts in the area of traffic assignment were initiated around 1950 to develop rational assignment techniques. In that year, the Highway Research Board summarized the practices of several states in assigning traffic to proposed routes (5).* Activities were then oriented toward developing empirical formulas to be used in estimating traffic diversion to expressway systems. The development of a systematic and efficient method of determining the minimum path through a maze in 1957 permitted the treatment of a transportation network as a unit (29). Most recent work on traffic assignment has been based on the minimum path premise.

Attention for the past six years has been directed toward the development of iterative procedures of traffic assignment to simulate

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*Numbers in parentheses refer to sources listed in the Bibliography.

traffic flow patterns. Many simulation techniques employ a capacity restraint to limit the assignment of trips within the traffic-carrying capabilities of the system facilities. Improvement of traffic operation on a transportation network by optimum assignment procedures is still in the early stages of development. Computer capacity is the major problem at the present time.

Purposes of Traffic Assignment

Traffic assignment is the allocation of trip interchanges to a transportation system. Various assignment techniques are used to reproduce travel patterns, to evaluate proposed plans and to optimize network flows. Present or future trip interchanges may be allocated to an existing or a proposed system in the different techniques.

In the reproduction of travel patterns, trip interchanges are assigned to the different facilities to produce traffic loadings comparable with those link volumes existing on the system. The techniques are employed to study the changes in flow patterns resulting from either a change in the operational controls or from an addition of new facilities to the system. The operational controls include one-way street operation, parking restrictions and special treatment of major intersections. The construction of expressways and interchanges and the widening of street segments are among the additions whose impact on the traffic flow patterns may be studied.

The use of traffic assignment for system evaluation features the allocation of trip interchanges to desire routes only. The assignment procedure is designed to determine the extent to which a system satisfies particular objectives. Deficiencies are obtained by comparing assigned volumes with available capacities. This comparative process is repeated until a practical plan is developed to accommodate the desired traffic interchanges for the selected design year.

When traffic assignment is used to determine the optimum flow patterns on a transportation network, trip interchanges are allocated to the street segments in a manner that optimizes a chosen objective function. The total cost or the total travel time spent by the drivers in their movements are examples of parameters used in defining such objective functions. Traffic engineering operational measures are then selected to regulate the traffic movement to achieve the optimum flow. Possible control measures include one-way street operation, parking restrictions, use of reversible lanes and the closure or metering of selected ramps on expressways.

Reproduction of Travel Patterns

Several models have been developed to reproduce travel patterns over a transportation system. Present methods can be placed in the following categories.

1. Trips are assigned to the "best" route only for each zonal interchange or "all or nothing" assignment.

2. Two routes are considered in the allocation of trips between each origin and destination or "diversion" assignment. The capacity restraint is often employed to produce a model that is representative of the real-world situation.

Diversion Curve Assignment

The use of diversion curves in traffic assignment was among the early attempts to reproduce travel patterns. In diversion assignment, a proportion of the traffic generated at a zone is assigned to an arterial system and the remainder to an expressway routing. Simulation of travel patterns by this technique is on a route basis; that is, a routing is developed to include the proposed expressway while the next best route includes only travel on the existing arterial system. Recent methods of this assignment technique incorporate capacity restraints for more realism in the reproduction of travel patterns.

Studies were conducted in the 1950's to compare expressway and alternate arterial route usage for selected trip interchanges. The basis of comparison was either a single parameter or a combination of several variables. When a single measure was used, the comparison was based on time saved (4, 41), distance saved (4), time ratio (9, 27, 41), distance ratio (41) or cost ratio (22). A typical diversion curve is shown in Figure 1. The diversion curves used in major urban transportation studies have been based on such combinations as distance and speed ratios or travel time and distance saved.

Detroit Metropolitan Area Traffic Study (2, 10). The diversion curves developed by the Detroit Metropolitan Area Traffic Study group are shown in Figure 2. Time and distance savings were selected as the most important considerations in the choice of a route (4). Indifference curves were formulated for various percentages of expressway use based on time and distance differentials. The application

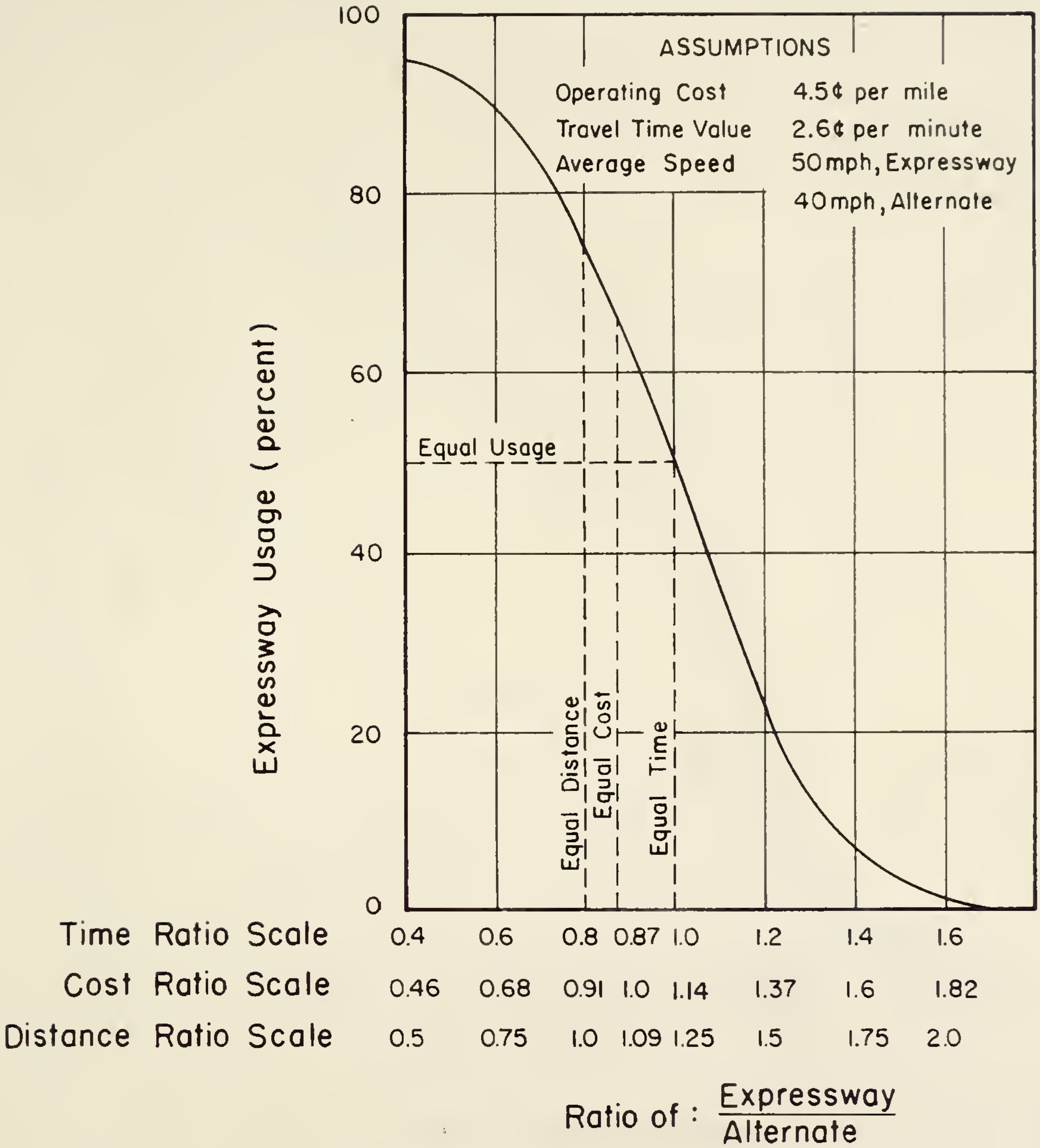

Fig. 1 Typical Diversion Curve

SOURCE: REFERENCE 36

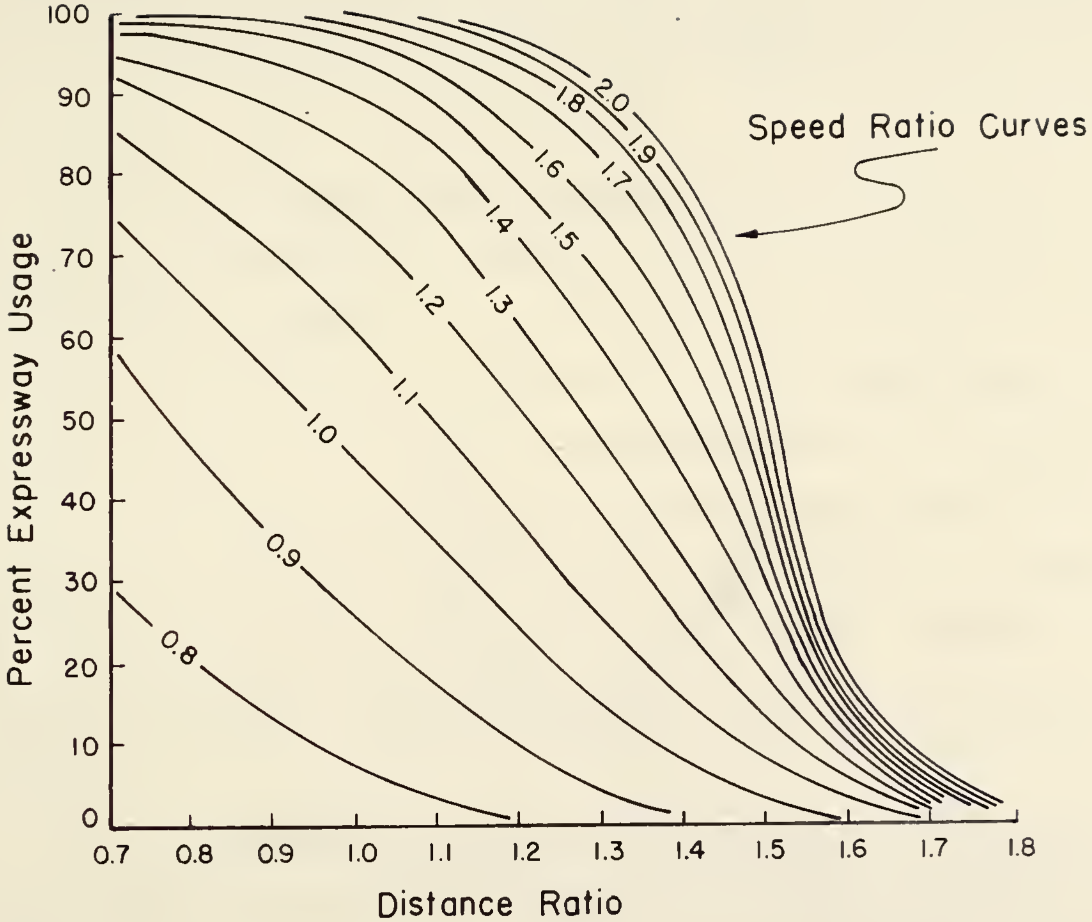

Fig. 2 Detroit Diversion Curves

SOURCE: REFERENCE 10

of these diversion curves was very difficult, and new curves were developed with distance ratio instead of distance differential and speed ratio instead of time differential as the decision-making parameters.

Because the Detroit study was performed before the minimum-path search through a maze was programmed, the following procedure was used.

1. The centroids of the network were coded by a system of coordinates.

2. The airline distances between zonal centroids were determined and multiplied by a conversion factor to obtain the best arterial street distances.

3. The minimum path for the expressway system was divided into three segments. Two segments were the connections from an origin to the expressway system and from this system to a destination. The remaining section was the portion of the route existing on the expressway system. The lengths of these three segments were computed separately and then added to obtain the minimum path for the expressway system.

4. The distance ratio and the speed ratio were computed and trip interchanges proportioned according to the relationship presented as Figure 2.

After the development of a computer program to find the minimum path through a network, the assignment procedures were programmed for both the expressway system and the arterial system. Distance is used as the parameter for path determination while diversion to the routes is made on the basis of the travel time ratio. A capacity restraint function is employed in the assignment of traffic to the arterial system (24).

A major drawback in the assignment method used by the Detroit group was the consideration of an expressway system as the only means of improvement for the existing network. Traffic loads are not determined on the individual segments of the system and, as a result, analyses of these links are not made to consider the effects of localized street improvements.

California Division of Highways. In an attempt to develop diversion curves for use in traffic assignment, the California Division of Highways made observations on the usage of two expressways in San Diego (31). A hyperbolic relationship describes the traffic diversion to freeways on a plot with distance differential as the ordinate and time differential as the abscissa. The equation for the family of diversion curves was selected as

$$P = 50 + \frac{50(d + mt)}{\sqrt{(d - mt)^2 + 2b^2}}$$

where P = percent of traffic diverted to a freeway.

d = distance saved in miles.

t = time saved in minutes.

m = a coefficient relating the value of a mile saved to a minute lost.

b = a coefficient determining the distance of the vertices of the 0 and 100 percent boundaries from the origin.

The values of "b" and "m" were chosen as 1.5 and 0.5 respectively. The resulting curves are shown in Figure 6.

Bureau of Public Roads (25, 40). The Bureau of Public Roads program of traffic assignment permits the optional use of diversion curves in the assignment procedure. The travel time ratio serves as the basis for proportioning traffic between two alternate routes. When the network is loaded by diversion assignment, two complete sets of "trees" are determined. The first set includes all the minimum paths from every origin to all destinations with the freeways as part of the transportation system. The second set of "trees" is composed of all minimum paths in the system without the freeway portions. Based on the ratio of the travel times for the two determined paths, a diversion factor is applied that proportions the trips to these two minimum paths. Simulation of travel patterns is then accomplished by applying the capacity restraint relationship to the impedance factors on the various links of the system.

The diversion curve assignment involves two independent paths and thus adds more realism for simulating actual traffic flow conditions than the single path approach. It is not justified, however, to assume that the condition of only two routes accounts for the possible paths accommodation of the trip interchanges between a pair of zones.

"All or Nothing" With Capacity Restraint

The traffic assignment techniques designed for reproducing travel patterns are summarized in this section. These procedures incorporate

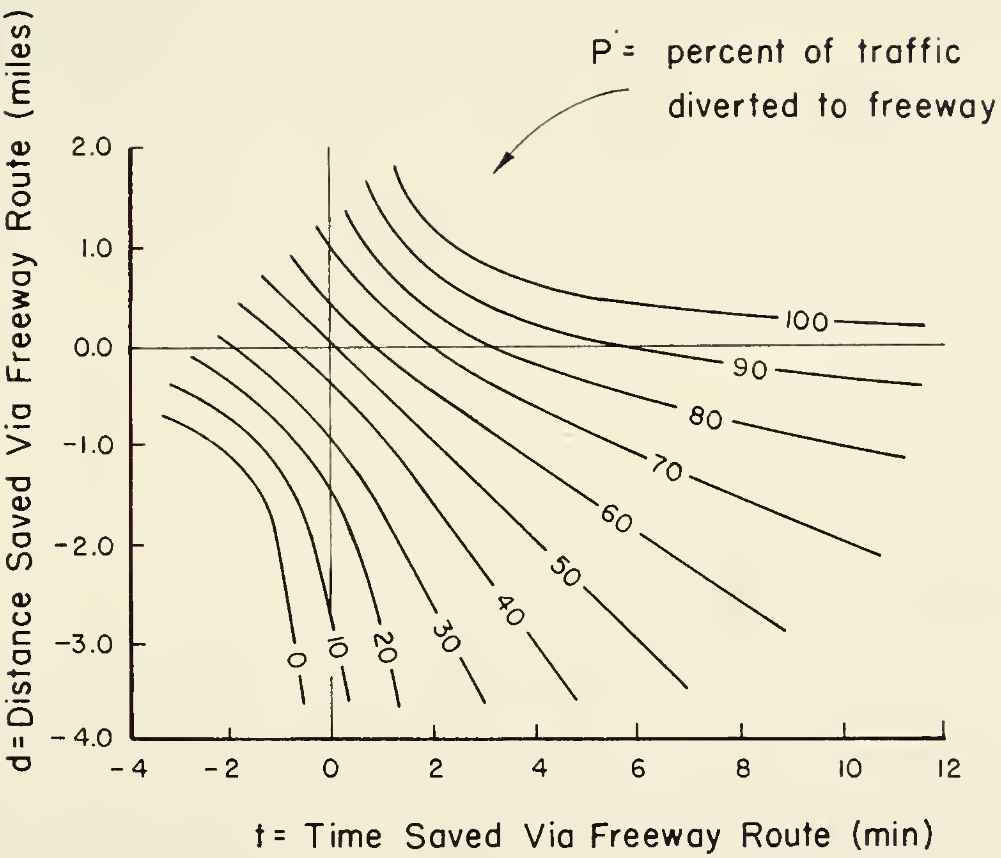

Fig. 3 California Diversion Curves

SOURCE: REFERENCE 31

a capacity restraint function and assign trip interchanges to the respective routes on an "all or nothing" basis.

<u>Chicago Area Transportation Study</u> (3, 6, 8). The Chicago Area Transportation Study, identified as CATS, developed a systematic computerized technique which incorporated the minimum path search to assign trip interchanges. This procedure reproduces travel patterns according to the following format.

1. Minimum-path trees are constructed from every origin to all destinations with the travel times for free-flowing conditions.

2. The trips generated at each zone are distributed to the various destinations using the determined minimum paths and the opportunity model.

3. Starting with the first zone, trip interchanges are assigned on an "all or nothing" basis to the respective minimum paths.

4. The accumulated volume to capacity ratio is computed for every link in the network, and the travel times are adjusted in accordance with the relationships shown in Figure 4.

5. After the travel times are modified to account for the traffic volumes resulting on the various links from the first assignment, the trip interchanges from the second zone are then assigned to the minimum path trees on an "all or nothing" basis.

6. This process is repeated until all zones of trip origin have been considered.

The order of zonal consideration influences the assignment outcome and is probably the greatest drawback in this procedure. Changing the order of loading may change the assigned volumes on the

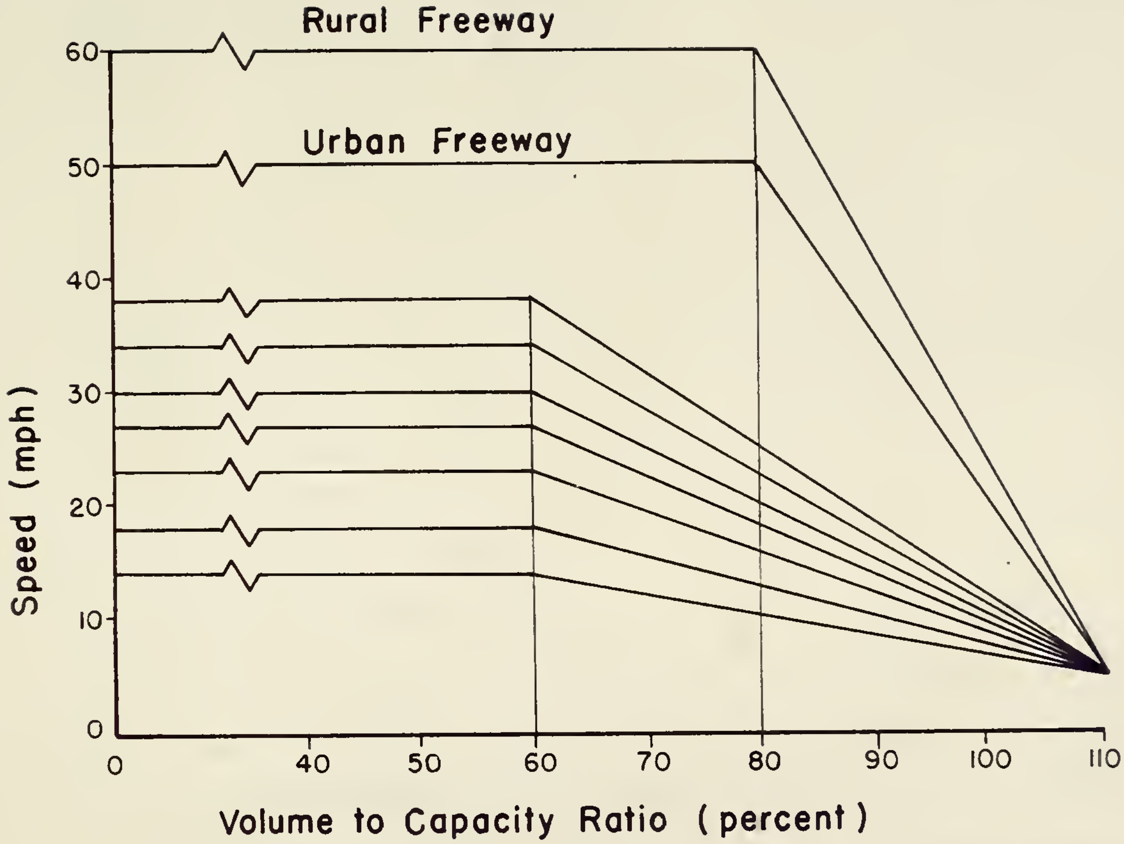

Fig. 4 Capacity Restraint Relationship
(Chicago Area Transportation Study)

SOURCE: REFERENCE 8

various links considerably. As a consequence, the ability to reproduce existing travel patterns does not guarantee that the assignment of the future trips to the network will reproduce future travel patterns. The "right" order of loading for best simulation results is not known and may vary in time with the increasing volumes of zonal interchanges.

Pittsburgh Area Transportation Study (34). The Pittsburgh Area Transportation Study method of traffic assignment is very similar to the previously discussed technique developed by the Chicago Area Transportation Study. The travel functions are updated after the consideration of a new zone, and the assignment is on an "all or nothing" basis for each set of new trees. However, the selection of zones was random in the Pittsburgh study and according to a specific order in the Chicago study. The capacity restraint relationship used by the Pittsburgh group is shown in Figure 5.

Wayne Arterial Assignment Method (37, 38). The Detroit Area Traffic Study and the Computing Center at Wayne State University developed a capacity restraint program of traffic assignment in 1961. In brief, the method comprises the following steps.

1. Minimum path trees are constructed from every origin zone to all destinations. The program of route selection is an extension of the Moore algorithm and is known as the branch method for arterial assignment. Travel times are computed from average speeds under typical urban conditions, and the nodes are coordinate coded for distance determination.

2. The first iteration is completed by assigning the zonal interchanges to the minimum paths on an "all or nothing" basis.

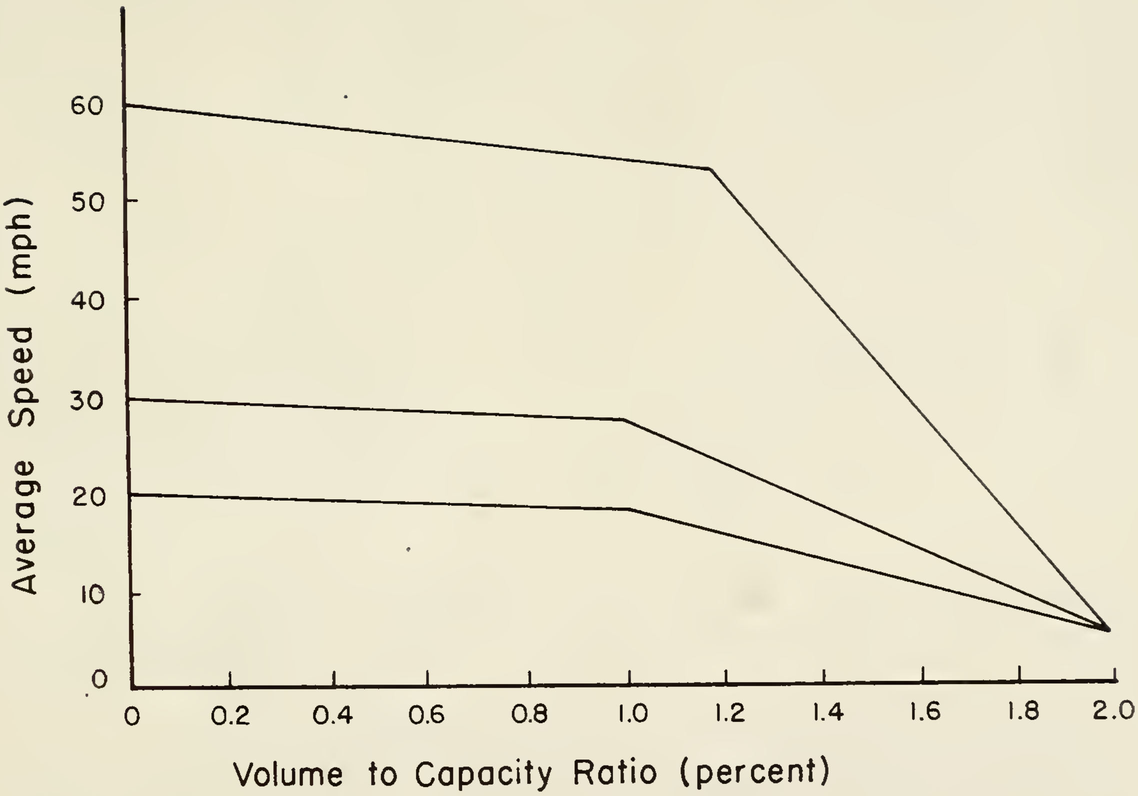

Fig. 5 Capacity Restraint Relationship
(Pittsburgh Area Transportation Study)

SOURCE: REFERENCE 34

3. After the ratios of assigned volume to practical capacity are determined for all links, the travel time on each link is adjusted according to the following capacity restraint function:

$$T_2 = e^{(R_1 - 1)} T_1$$

where T_2 = revised travel time for use in the second iteration.

R_1 = ratio of the assigned volume in the first iteration to the practical capacity.

T_1 = travel time used in the first iteration.

e = 2.71828.

4. A new set of minimum path trees is constructed with the altered travel times obtained in the previous step.

5. Trips are assigned to the new trees on an "all or nothing" basis.

6. The volumes assigned to the different links are averaged for the various iterations.

7. Each succeeding iteration is performed by repeating the above steps and employing the capacity restraint relationship shown in Figure 6.

8. The procedure is repeated until little volume change occurs with further iterations.

The above method is designed to simulate travel over a network and not to analyze or evaluate a transportation system. Although the technique might permit the comparison of the traffic flows over two or more proposed plans, it provides no means of ascertaining the extent to which these plans meet the study objectives.

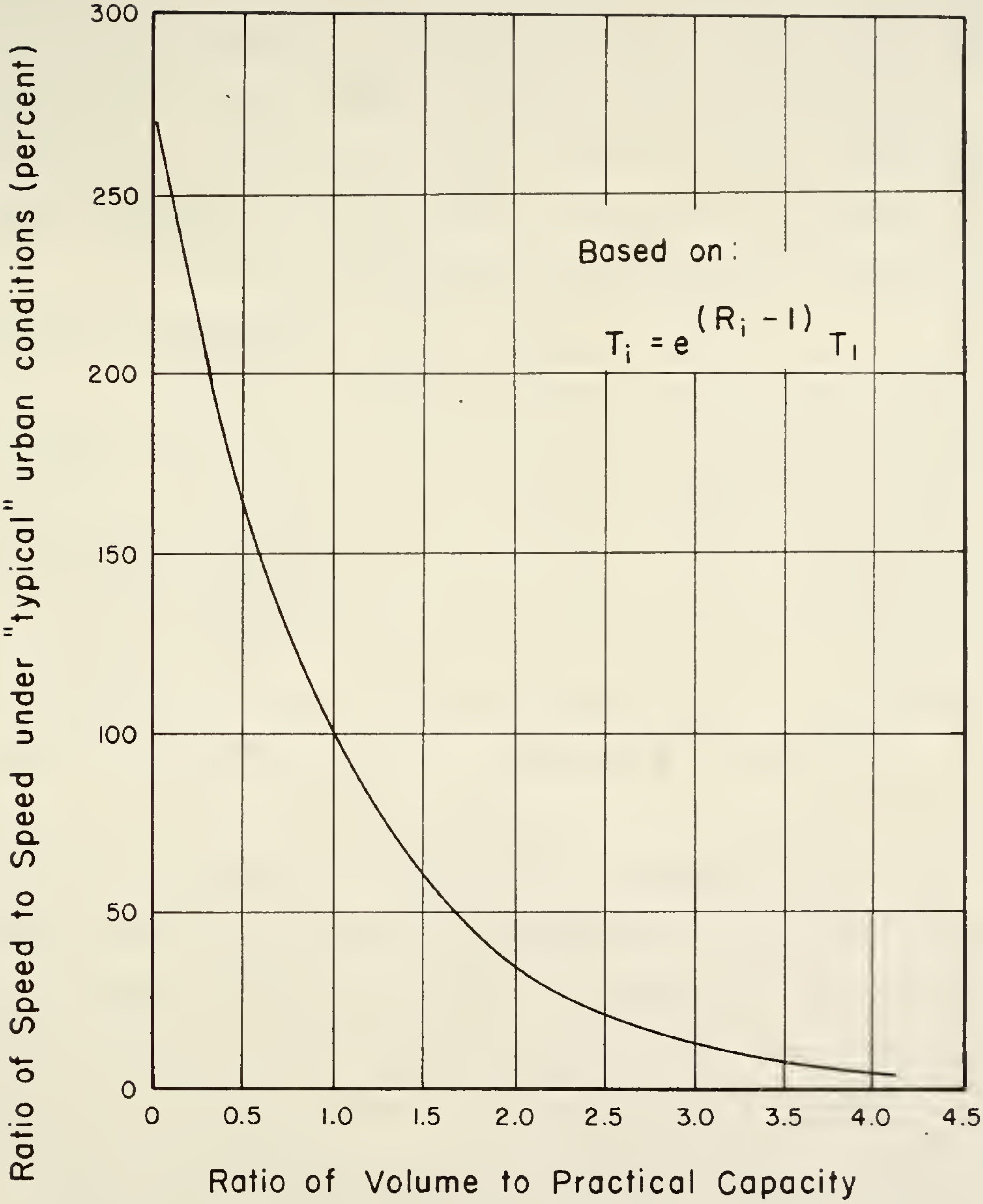

Fig. 6 Capacity Restraint Relationship
(Wayne Arterial Assignment Method)

Traffic Research Corporation (14, 18, 19). The assignment method developed by the Traffic Research Corporation combines trip distribution and traffic assignment. In addition, multi-mode travel can be treated in the reproduction of travel patterns. Capacity restraints are specified in the selection of routes and in the choices of destination, route and travel mode. The following steps comprise this method.

1. The study area is divided into zones, and the person trips generated are determined for each zone.

2. For one or more travel modes, the minimum path routes are determined based on "ideal travel times" corresponding to free-flowing conditions. These routes for automobile, transit, mixed and truck movements are called "ideal routes".

3. The time factor, the modal split factor and the assignment factor are next calculated from the derived paths. The time factor describes the effect that travel time has on the propensity of travelers to travel between an origin and a destination pair. The modal split factor determines the portion of traffic that uses mass transit. The assignment factor describes the proportion of trips from an origin to a destination on a particular mode and specifies a route for that mode of travel.

4. By using the calculated time factors and a modified version of the gravity equation, person trips are distributed from each zone to the various destinations on the basis of their relative attractiveness.

5. The modal split and assignment factors are employed to determine the number of person trips that travel on each mode and on

each route within the mode grouping. The trips assigned to particular facilities are the product of the modal split factor, the assignment factor and the total person trips generated in each zone.

6. Trips within a mode class are assigned to the respective routes on an "all or nothing" basis and person trips by automobile or surface mass transit are converted to automobile trips.

7. The travel times are adjusted for the calculated loads on the various links by use of the capacity functions shown in Figure 7. Buses and streetcars are converted to equivalent vehicles.

8. The sequence of steps 2, 3, 5 and 6 is repeated to develop alternate paths and subsequent assignments. A total of nine routes between an origin-destination pair can be handled for all travel modes.

9. Trip distributions are modified in accordance with the new time factors. New trip distributions are obtained by repeating steps 2, 3, 5 and 6. This procedure is iterated until changes in link volumes from one solution to the next remain less than some predetermined value.

Although the method developed by the Traffic Research Corporation to simulate travel patterns is probably the most comprehensive procedure attempted, a large number of iterations are required to attain convergence.

Bureau of Public Roads (40). The "all or nothing" assignment recommended by the Bureau of Public Roads comprises the following steps.

1. The minimum-time path from an origin to all destinations is selected using an extension of the Moore algorithm (29). The complete set of these paths is referred to as a "tree", and the process

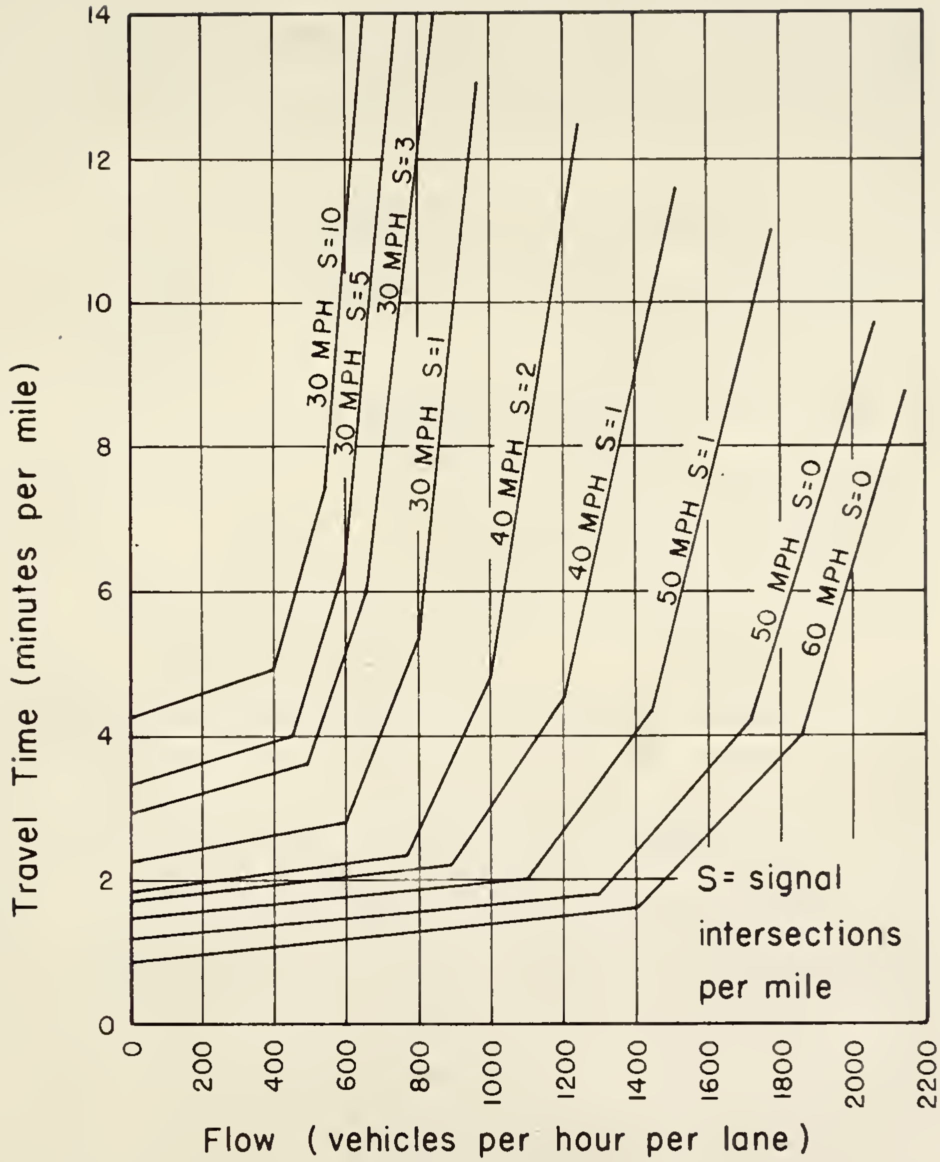

Fig. 7 Capacity Restraint Relationship for Roads With Cars Only (Traffic Research Corporation)

SOURCE: REFERENCE 19

is repeated for all input nodes which are known as centroids for the zones.

2. Trips originating at a centroid are assigned to the minimum-time paths emanating from that centroid. The order of loading is not considered when this technique is applied to all centroids in the system.

3. Based on the assigned volumes and the practical capacities of the different links, new travel times are computed according to the following relationship:

$$T = T_o \left[1 + 0.15 \left(\frac{\text{Assigned volume}}{\text{Practical capacity}} \right)^4 \right]$$

where T = travel time at which the assigned volume can travel on the subject link.

T_o = base travel time at zero volume.

The relationship is shown graphically in Figure 8 using speed in place of travel time.

To moderate the change in loading characteristics which result from updating the travel times, only one quarter of the change between T and T_o is added to the base travel time. The updated travel time to be used in the next iteration is

$$T' = T_o + \left(\frac{T - T_o}{4} \right)$$

where T' = revised travel time on the subject link.

Another method of moderation is to take the modified travel time as the average between T and T_o.

4. A new set of trees is built using the altered travel time values. The base equation for revising the travel times has the effect

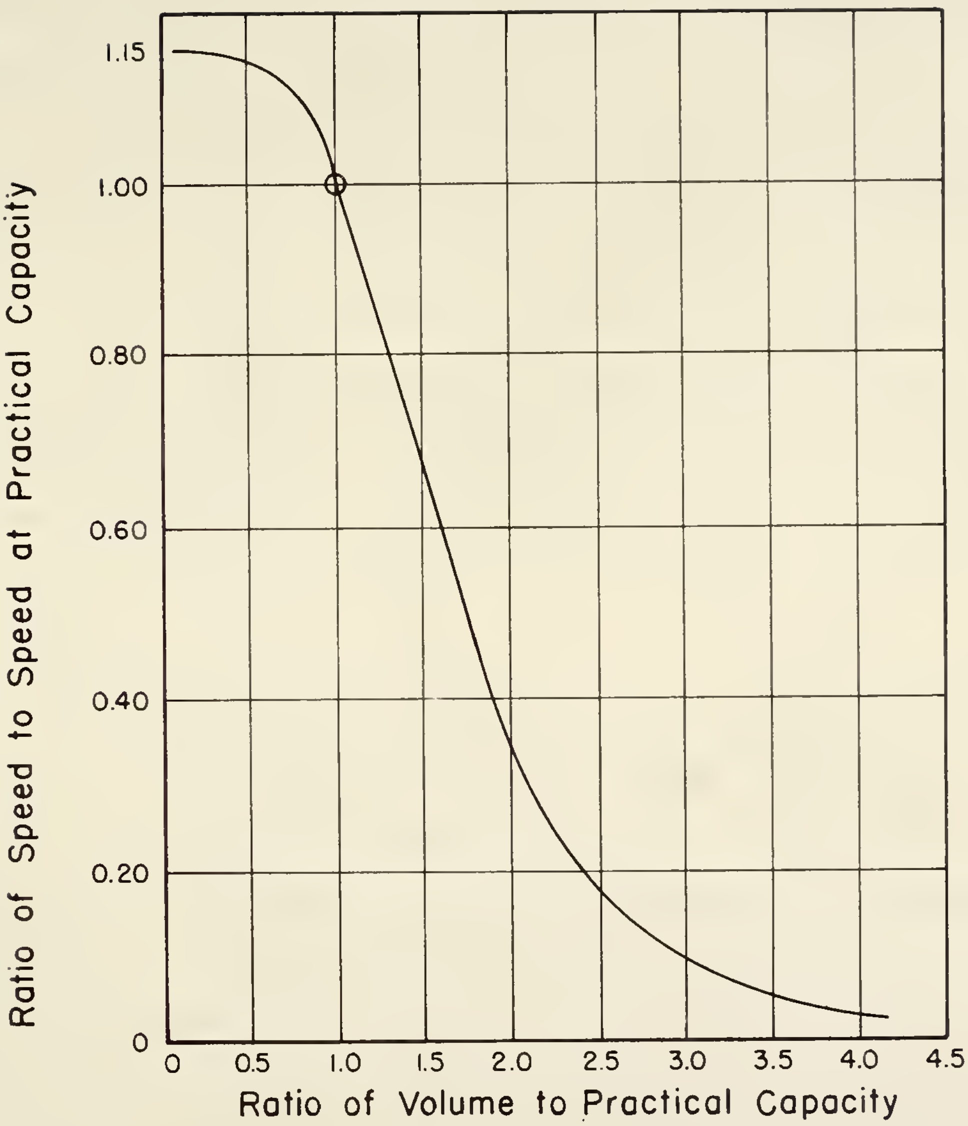

Fig. 8 Capacity Restraint Relationship
(Bureau of Public Roads)

SOURCE: REFERENCE 40

of making links with volume to capacity ratios greater than one less desirable in the route selection process. Conversely, links with volume to capacity ratios less than one become more desirable when searching for new minimum-time paths.

5. Trip interchanges are again assigned to the new set of minimum paths, and the travel times are modified in accordance with the volume to capacity ratios for the various links.

6. The above procedure of minimum-time path selection and subsequent trip loading is reiterated until acceptable comparisons are obtained between field counts and assigned volumes. A satisfactory assignment is usually accomplished in six iterations. The assigned volume on each link is calculated as the average loading for all iterations.

In the assignment process, this model is first applied to the present trip interchanges on the existing network. The Bureau of Public Roads recommends this step to insure that the model reproduces existing travel patterns. After this verification has been performed, the technique is applied to the assignment of future zonal interchanges to reproduce future travel patterns.

Because this assignment is devised to simulate traffic flow, travel desires or system deficiencies are not evaluated by this procedure. The use of the BPR model to reproduce travel patterns encompasses the following shortcomings.

1. The Bureau of Public Roads manual on traffic assignment states that the total "weighted error" is a measure of the accuracy of the traffic assignment (40). The total "weighted error" obtained by

comparing assigned volumes with field counts has ranged between 33 and 46 percent for most assignments made with this method (16). Thus, considerable error has resulted in this simulation procedure.

2. When the technique is employed with a proposed system, balanced volumes may result on a badly planned network. A transportation system could be proposed with planned freeways perpendicular to major desire lines, and the assigned volumes are within the acceptable link capacities because sufficient system capacity is available to accommodate the total trip interchanges. However, many trips will be made in a circuitous fashion.

Evaluation of Proposed Plans

At the present time, an analytical method is not available to evaluate the ability of a transportation system to meet the study objectives. Deficiencies are ascertained only in an approximate manner by crude techniques. A capacity restraint model does not reflect travel desires or test the adequacy of a proposed plan. This technique is used to obtain the anticipated traffic flow patterns on an already-developed plan. The analysis of the resulting flow patterns does not provide a basis for plan evaluation because the travel desires and the study objectives have not been incorporated in the assignment procedure.

"All or nothing" assignment without capacity restraint has been used to obtain an estimate of network deficiencies (44). Trip interchanges are assigned to the set of best routes with no regard to capacity limitations. The resulting assignment gives a general picture of the drivers' desires under free flow and free choice conditions.

This approach aids in the planning of proposed transportation facilities and in their location.

Similar results can be obtained using a "spider" network. After centroids are connected by straight lines that represent the desire paths, trip interchanges are assigned to these paths. The graphical representation of the assigned trips provides a means for further analysis of the network.

Another method used to assist in the development of a proposed plan is known as corridor analysis (12). The study area is traversed by two perpendicular sets of straight lines. These lines are called analysis screen lines or corridor lines and may be oriented at any angle to the street system. Trips are assumed to originate and terminate at the centroids of zones, and desire movements are represented by straight lines joining all pairs of centroids. When a desire line crosses an analysis screen line segment, the desire volume is tabulated at that location. Movements crossing every analysis line are summed, and the resulting volumes are plotted to scale on a base map of the study area. The difference between the desire volumes for a line section and the capacities provided by the streets crossing that section is a measure of the link deficiency. This information assists in determining the nature and the location of proposed facilities. Radial and circumferential movements can be studied similarly by considering circumferential and radial corridors.

As mentioned earlier, these methods give only rough estimates of the travel desires. No technique presently exists to evaluate the adequacy of a transportation plan quantitatively.

Optimization of Network Operation

When traffic assignment is used to improve traffic flow conditions over a given street network, trip interchanges are assigned to various routes in a manner that optimizes a particular objective function. Overall travel time, distance, cost, any other parameter or combination of parameters may be used to quantify the objective function. From the developed flow patterns, certain operational measures are selected to regulate the traffic flow on the real network to achieve optimum operation. These measures may include one-way street operation, parking restrictions, closure or metering of selected ramps on an expressway and the use of reversible lanes.

One approach to the solution of the optimum-flow problem has been linear programming. In 1963, J. A. Wattleworth and P. W. Shuldiner illustrated the use of linear programming in the "optimum" assignment of trip interchanges to a network (4[illegible]). No capacity restraint was employed, and the simplex algorithm was used for solution. Left-turn penalties were considered by adding dummy links to the network at the various intersections.

A. Charnes and W. W. Cooper developed a procedure called the "multi-copy" method to solve the linear programming problem of optimum assignment (7). C. Pinnell and G. T. Satterly demonstrated the application of this method to the assignment of traffic using a capacity restraint function (33). The computer program for the application of the method is limited in its use to 50 input nodes, 60 capacitated links, 300 network nodes and 1000 links (32).

The "multi-copy" model derives its name from the association of a network copy with each traffic origin in the network. The linear programming statement of the problem is as follows:

Minimize

$$C = \sum_j c_j x_j^{\alpha}$$

subject to

$$\sum_j \varepsilon_{ij} x_j^{\alpha} = \Xi_i^{\alpha}$$

$$\sum_{\alpha} x_j^{\alpha} \leq \Delta_j$$

$$x_j^{\alpha} \geq 0$$

where C = objective function.

c_j = travel cost (in time units) on link j.

x_j^{α} = amount of traffic (number of vehicles) assigned to link j on copy α.

ε_{ij} = incidence number for the j-th branch at the i-th node (+1 for input, -1 for output, zero if not connected to a node).

Ξ_i^{α} = influx or efflux at the i-th node on copy α.

Δ_j = capacity limitation (number of vehicles) on link j.

By use of a change of variable, the unknown in the problem is altered from the amount of traffic on a link for a specific copy (x_j^{α}) to a percentage of a given extreme point solution. The problem is thus transformed into the following format.

Minimize

$$C' = \sum_{\alpha=1}^{m} C^{\alpha T} \lambda^{\alpha}$$

subject to

$$A^{\alpha} \lambda^{\alpha} = b^{\alpha}$$

$$\sum_{\alpha=1}^{m} K^{\alpha} \lambda^{\alpha} \leq d$$

$$\lambda^{\alpha} \geq 0 \qquad (\alpha = 1, 2, \ldots m)$$

where C' = transformed objective function.

C^{α} = cost vector for copy α. Individual element C_j^{α} is the cost on link j for copy α.

λ^{α} = solution vector for copy α. Individual element λ_j^{α} is the number of vehicles assigned to link j on copy α.

A^{α} = matrix of incidence numbers for copy α.

b^{α} = vector of node influxes or effluxes for copy α. Individual element b_j^{α} is the influx or efflux at node j on copy α.

K^{α} = matrix of structural coefficients (1 or 0) which specifies the capacitated links on copy α.

d = vector of capacity constraints. Individual element d_j is the limiting capacity on link j.

A modified simplex method is then used to solve the problem where the volume-delay interaction is treated by a piece-wise linear approximation.

Another approach to solving the problem of optimal assignment to a network is the application of the maximum principle (45). The problem statement is to find a sequence of $\theta^{n,m}$ in which n = 1,2...N and m = 1,2...M, to maximize $\sum C_i X_i^{N,M}$

where $\theta^{n,m}$ = decision variable vector for node (n,m).

C_i = specified constant associated with link i.

$X_i^{n,m}$ = state variable vector representing the number of vehicles leaving node (n,m) on link i.

The procedure in solving the problem is first to assume a set of decision variables. Work then proceeds forward from an original node and backward from a destination node to obtain a desired value for the decision variables. The process is repeated until two successive sets of decision variables are identical. Four iterations are needed to solve a 2x2 network problem using a linear time function. The maximum principle has the advantage of treating the volume-delay interaction as a non-linear relationship (11, 39).

In 196?, W. L. Mosher developed an analytical matrix technique to load a network in an optimum manner (40). The objective function is either to minimize the "figure of merit" for the entire system or to equalize the path "figure of merit" over appropriate sets of paths. The figure of merit is taken as the cost per unit of flow. The algorithm incorporates capacity restraint but, like other optimization techniques, is limited in its application to small networks.

CONCEPTUAL MODEL FOR SYSTEM EVALUATION

Metropolitan transportation studies have as an objective the preparation of transportation plans. These plans are continuously updated to take into account actual community development. Planning, as a consequence, is a continuous and dynamic process. Yet, designs are prepared in an urban transportation study for a particular stage in the growth of the community. A study year is chosen, and plans are prepared to accommodate the traffic demands for that particular year.

The adequacy of a proposed plan is evaluated by studying the degree to which the design satisfies the study objectives. These objectives are described in either absolute or relative criteria. Absolute criteria specify boundary conditions for selective features of a plan. An example of absolute criteria is an upper limit on the cost of a transportation system. Relative criteria, on the other hand, define the relation between the benefits accrued from a plan and the costs incurred to provide the necessary physical improvements. Achieving the maximum user benefits per dollar spent is an example of this type of criteria.

The general community goals pertain to optimizing the total environment of man and include such specific activities as transportation, land use, resources, and social and economic considerations. It is often difficult or impossible to quantify the various activities, and decisions are reached by subjective decision-making. The interactions among these goals are very complex. Although general agreement exists as to the need for a plan that best satisfies all community objectives, definite and rational procedures are not available to accomplish the desired end results.

The use of absolute criteria for system evaluation permits the consideration of the community goals separately. Upper or lower limits are established to define minimum standards for physical, social and economic objectives. A plan that does not meet these objectives should not be considered in the decision-making process. Examples of these absolute criteria are an upper limit on noise, a preservation of a minimum amount of recreational space and a lower limit on overall travel speeds.

Level of Service Concept

In this research, the transportation goals of a community are represented by the attainment of specific levels of service for chosen trip interchanges in an urban area. Cost and technology limit the feasible range of these service levels and make them time and community dependent criteria. Standards that are acceptable to a particular community may be rejected by another urban center. Similarly, an acceptable level of service may vary over the years in a particular community.

The levels of service that are considered acceptable by people are hard to define without the inclusion of economic and environmental limitations. The belief that the transportation system can be improved prevails and will continue to exist as long as people feel that technology is able to provide them with better levels of service for urban travel. Their evaluation often reflects desires unbounded by financial constraints.

Urban transportation studies recognize the expanding nature of people's desires for better transportation facilities. The plans developed by these studies are nevertheless limited in scope by the capital and operating funds allotted to transportation improvements. These expenditures must be based on the total needs of the community, and a balance should be attained in the realization of various community goals.

Complete flexibility in the development of a plan is achieved by the use of service levels to describe the community objectives as related to transportation. This approach permits total, partial or no improvements in the existing levels of operation on a system. An existing network may be adequate for a future year if the community is willing to accept reduced levels of service. Conversely, an expensive plan based on a high performance of operation is justifiable as long as the people desire and are willing to pay for its implementation.

The level of service concept aids in the selection of preferential improvements on a transportation system. Selected trip interchanges may be given higher levels of service than other traffic movements. The resulting plan would favor these preferred trips by providing them with superior travel qualities.

Basis of the Assignment Procedure

Between an origin and a destination pair of urban zones, routes or corridors of travel exist to expedite the flow of traffic within established levels of service. The number of these acceptable routings depends on the characteristics of the transportation system and the chosen service level. An acceptable route may not be available for some trip interchanges, and zonal deficiencies exist for the selected service levels. On the other hand, other interzonal transfers may have one or more acceptable routes.

These routes can move traffic at the chosen levels of service as long as the traffic volumes do not exceed specific upper limits referred to as service volumes. When these volumes are surpassed, the interzonal service level drops to a value below the acceptable limit. Service volumes are a function of the operational characteristics of the routes and the desired quality of traffic flow. The volume of traffic a route can accommodate under free flow conditions is different from that under capacity flow conditions. The choice of the proper quality of traffic flow is a decision made by the planning team to reflect desires and financial limitations of the community.

The establishment of the interzonal levels of service and the quality of traffic flow on the links of a system sets a limit on the number of available acceptable routes. When higher service levels are desired, the number of acceptable routes is reduced. Similarly, the choice of a better quality of traffic flow results in fewer acceptable corridors of travel. The acceptable routes thus delimit the network that is available to accommodate the projected traffic interchanges within the limits of the study objectives.

After the acceptable routes have been developed according to the specified levels of service, the relative attractiveness of these routes is determined for the movement of traffic between selected origin-destination combinations. Trip interchanges are then assigned to these routes on a proportional basis in accordance with the relative attractiveness of these routes. This form of traffic assignment reproduces travel desires as dictated by the appropriate levels of service and quality of traffic flow selected. The qualities of traffic flow are specified in accordance with the chosen levels of service for the various trip interchanges.

The determination of acceptable routes between an origin and a destination and the subsequent allocation of trip interchanges to these routes are not limited in application to vehicular movements. An acceptable path between the zonal pair may be obtained by use of mass transit facilities, and the routes to which the trip interchanges are assigned can include single or multi-mode connections. The trips are again assigned on a proportional basis in accordance with the relative attractiveness of the routes and modes. The attractiveness indexes express the relative desirability to use particular modes of travel and specific routes within these modal groups.

System Evaluation

The application of the above assignment procedure may result in one or more of three possible outcomes - zonal deficiencies, link deficiencies or no deficiencies.

Zonal Deficiencies

Zonal deficiencies occur when no acceptable routes exist to move traffic between chosen zones at specified levels of service. No interzonal transfers between these two zones can be accommodated by the considered system and, as a consequence, can only be handled by improvements or additions to the available facilities. This situation is produced by the nature of the variables used in the assignment technique. High interzonal levels of service or a superior quality of traffic flow may preclude the existence of any acceptable routes. Absence of an acceptable connection also results from the consideration of a transportation system of an inferior quality.

Link Deficiencies

The allocation of trips to the alternate acceptable routes between origin-destination combinations may result in the overloading of some links on these routings. Overloading of a link occurs when the assigned number of trips exceeds the designated service volume for that link. A link deficiency is the difference between the assigned trips and the service volume on a particular link. When link deficiencies exist, selective improvements on the transportation system are needed at or near the overloaded link to accommodate the excess traffic.

No Deficiencies

The assignment of trip interchanges to the transportation system may result in no zonal or link deficiencies for the entire urban area. Because non-deficient links are able to carry the assigned volumes of traffic at the prescribed levels of service, no improvements are required on these links.

Depending on the nature and magnitude of the obtained deficiencies, a plan is developed to accommodate the excess traffic. The ability of a plan to meet the desired objectives is then tested by assigning the set of trip interchanges for the design year to the proposed network. The adequacy of a transportation system is confirmed when all interzonal transfers are accommodated without zonal or link deficiencies.

Simplified Proportional Assignment Technique (SPAT)

This process of system evaluation is identified as the Simplified Proportional Assignment Technique or simply SPAT. The concept underlying the assignment technique is based on the premise that a transportation system provides selected levels of service for particular trip interchanges. A plan is evaluated by considering the degree to which these travel objectives are satisfied.

A diagrammatic representation of SPAT is illustrated in Figure 9. The process, which may be applied for the evaluation of any transportation plan, includes the following basic operations:-

1. Appropriate levels of service are selected for various trip interchanges within the study area. These service levels are predicated on the study objectives as related to the transportation requirements and the financial limitations of the community.

2. The desirable qualities of traffic flow on the various components of the transportation system are determined for the selected levels of service and the characteristics of the street or transit line sections. This step establishes the service volumes that different sections of the system are able to accommodate at various levels of service.

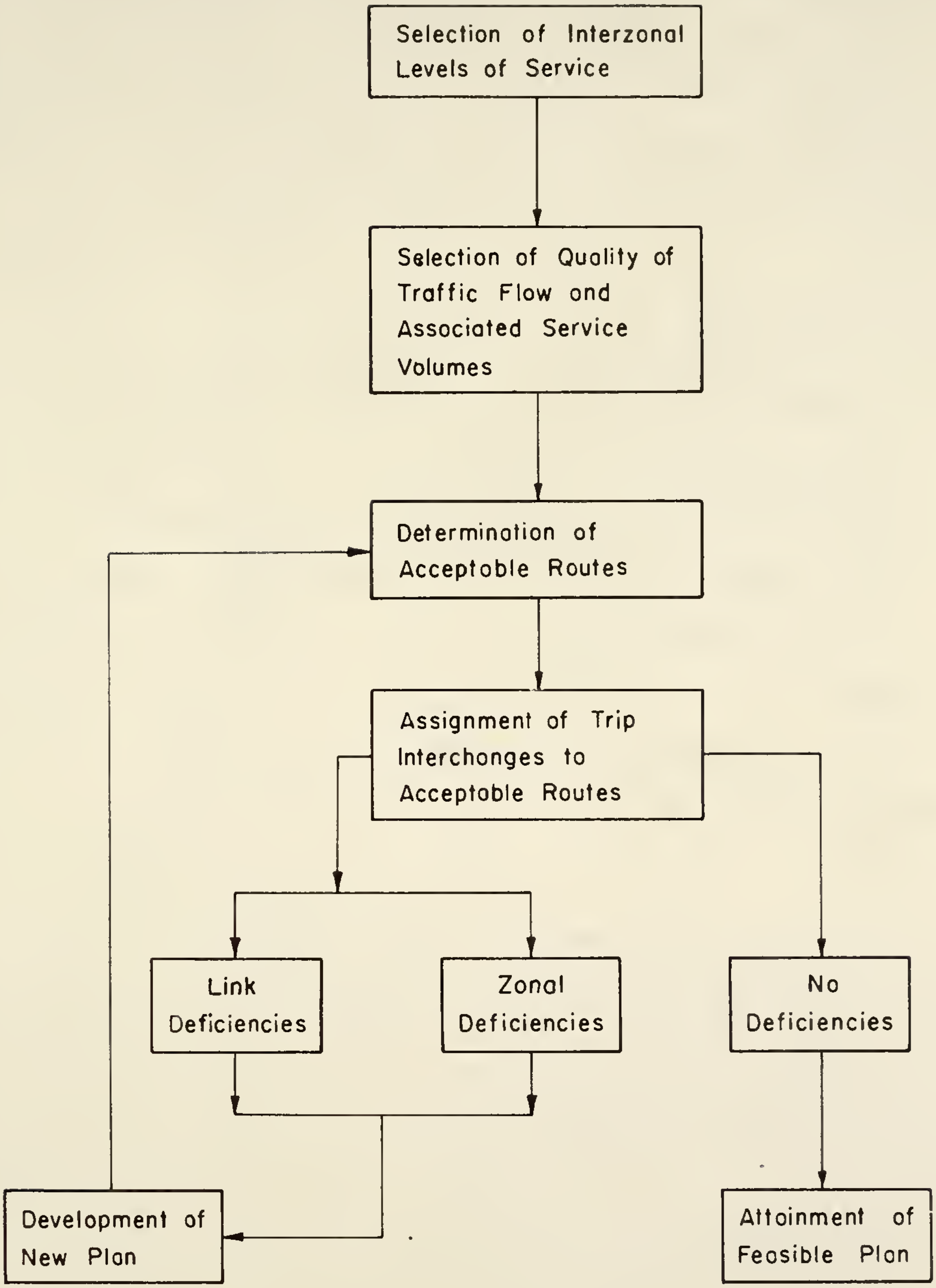

Fig. 9 Logic Diagram of the Simplified Proportional Assignment Technique

3. All acceptable routes are determined that connect chosen pairs of urban zones. Acceptable routes include only corridors of travel which are capable of moving traffic between an origin and a destination at the chosen level of service and quality of traffic flow. One or more modes of travel may be included in the search for these routes.

4. Trip interchanges are then assigned to the travel corridors on a proportional basis reflecting the relative attractiveness of these corridors.

5. Any deficiencies in the system are zonal and/or link deficiencies. A zonal deficiency results from the absence of an acceptable route to which a given set of trip interchanges may be assigned. A section that is assigned more trips than its service volume has a link deficiency. The proposed improvements on the system are designed to accommodate the excess traffic associated with both link and zonal deficiencies.

6. The assignment procedure is used to evaluate the extent to which a proposed plan satisfies the study objectives. The adequacy is confirmed by the ability of the plan to provide the chosen levels of service and qualities of traffic flow for all trip interchanges within the study area.

EVALUATION OF THE CONCEPT PARAMETERS

The various components of SPAT were identified and the associated parameters evaluated to permit the application of the proposed concept to urban transportation studies. There are two types of parameters employed in the assignment procedure. The first class of parameters refers to the items requiring quantification by the planning team. Because these variables are closely related to the study objectives and policies, their evaluation depends on the goals of the community for which the study is performed. The other parameters are related to the computational aspects of the assignment technique. Measures for these variables can be established and used in conjunction with the assignment procedures for any transportation study.

Only suggested values for the decision-making parameters which are specified by the planning team are presented in this study. These parameters include the service levels that define the study objectives and the desired qualities of traffic flow on the different sections of the transportation system. The values proposed for these variables are based on work performed in related areas because the proposed technique (SPAT) has not been utilized by an operating agency.

The parameters which are related to the procedural aspects of the Simplified Proportional Assignment Technique are quantified in later sections. This work includes the identification and determination of acceptable routes and the development of procedures for proportioning the trip interchanges to these selected routes.

Definition of Study Objectives

A plan is evaluated by determining the degree to which the design features satisfy the stated objectives. The community objectives in relation to the desired transportation services are expressed by desired levels of service for trip interchanges between pairs of urban zones. When SPAT is used to evaluate an existing or proposed transportation system, these service levels are considered in the search for acceptable routes and in the assignment of trip interchanges to these routes. An acceptable path is determined on the basis of satisfying a chosen level of service. The route attractiveness used in proportioning trips among alternate routes measures the degree of attainment of particular service levels.

Numerous attempts were made to identify the factors associated with a level of service on an urban facility. Although the driver's motivation on a particular trip encompasses a wide spectrum of possibilities, four basic factors have been considered indicative of this motivation. These factors are listed as travel time, operating cost, safety and driving satisfaction (35). The choice of the appropriate factor, or combination of factors, to describe a level of service greatly depends on the purpose of the trip. Work trips, which constitute a major portion of the total travel movements in an urban area, are selected primarily on the basis of travel time. This condition has led many agencies to use travel time as the sole factor to rate the desirability of route usage.

Two approaches to the treatment of the level of service are possible when SPAT is applied to the evaluation of a transportation system.

1. All factors defining the level of service are considered in the choice of the acceptable routes and in the subsequent assignment of the trip interchanges to these routes.

2. The acceptable routes are selected on the basis of travel time only. The other factors that define a level of service are considered in the proportional assignment of trips to these routes. The same outcomes result from the application of these two methods. A desire assignment is achieved where the links are assigned volumes of traffic in accordance with the satisfaction of the service levels by the routes involved.

The adoption of the second approach in the use of the Simplified Proportional Assignment Technique features two major advantages. First, only one variable is used to rate the various sections of the transportation system. The inclusion of factors having non-comparable units in one service level expression is not warranted because arithmetic operations are not possible on combinations of these factors. Second, this approach provides the desired flexibility in the evaluation of the service level components. The quantification of these components is needed only for proportioning traffic, and, as a consequence, different ratings of such components for different trip purposes are easily incorporated into the proportioning procedure.

Although travel time is only one of the factors associated with level of service, its use in the search for alternate routes includes all paths satisfying the specified level of service. The subset of routes that meet a service level restriction is totally enclosed in the set of acceptable routes satisfying the travel time component only.

The total travel time is not a realistic parameter to define the study objectives because interzonal distances change for different zonal pairs. For a systematic computational procedure, the overall travel speed is a more appropriate parameter than the total travel time. This change in variable does not affect the determination of acceptable routes; instead, it permits the expression of the study objectives in more convenient measures.

The acceptable overall speeds to be used in the Simplified Proportional Assignment Technique may vary with study communities. The appropriate values are dependent, among other things, on the economic base and stage of development of the community and on the purposes of the trip interchanges. The National Committee on Urban Transportation has established minimum recommended standards for overall travel time as a function of airline distance (1). The values are presented in Table 1. The following relationships represent expressions of travel time in terms of airline distance for the recommendations of the National Committee on Urban Transportation.

$$T = 1.705\ D + 0.095 \qquad \text{for } D < 1$$

$$T = 4D - \frac{D^2}{4} \qquad \text{for } 1 < D < 4$$

$$T = 2D + 4 \qquad \text{for } D > 4$$

where T = maximum travel time recommended in minutes.

D = airline distance between zonal centroids in miles.

TABLE 1

Minimum Recommended Standards for
Overall Travel Time

Airline distance (miles)	Max. travel time (minutes)	Min. average speed (miles per hour)
2	7	17.1
4	12	20.0
6	16	22.5
8	20	24.0
10	24	25.0
12	28	25.7

SOURCE: REFERENCE 1

While the suggested figures consider differences in trip lengths, the values do not account for variations in trip purpose.

Selection of the Quality of Traffic Flow

Another evaluation parameter which may quantitatively vary from a study to another is the desired quality of traffic flow on various segments of the transportation system. When this value is coupled with the interzonal levels of service, the qualities of traffic movement establish the nature and complexity of an adequate plan. An expensive plan results from the selection of high interzonal levels of service and a superior quality of traffic flow. On the other hand, little or no improvement may be needed on an existing system if sufficiently low standards are adopted for both the interzonal levels of service and the quality of movement. It is possible to accept the same plan for high service levels and low traffic flow qualities as for low service levels and high flow qualities.

The quality of traffic flow recommended for use in this evaluation of transportation systems corresponds to the level of service "C" as specified in the Highway Capacity Manual (13). This link level of service is indicative of stable flow conditions in which most drivers experience some restrictions in the traffic stream. If superior traffic flow qualities are desired or inferior traveling levels of service are acceptable, levels "B" or "D" may be used respectively.

Acceptable routes in a network are determined on the basis of impedance factors that are assigned to the various links. The impedances employed in the assignment process represent the desired qualities of traffic flow on the various parts of the system and are evaluated according to the selected link levels of service. These impedances are expressed as travel times or speeds on the links of the transportation system. Because the assignment technique is designed to reflect travel desires and not to reproduce flow patterns, the impedances used in route determination are not revised after allocating the trip interchanges to the system.

Zonal deficiencies occur when interzonal transfers are not assignable to any route. This condition results from the absence of a path that can accommodate traffic between two selected zones at a pre-set level of service. It may be possible, however, to assign part of these deficiencies at the established service level to some routes on which little traffic has been assigned. These low-volume routes are not detected because of the relatively high impedance factors used in the search for acceptable paths.

To insure that the adopted zonal deficiencies do not include assignable trips, the following procedure was adopted.

1. The assignment technique is applied to the transportation system using the desired quality of traffic flow to determine the zonal deficiencies. This step is defined as the basic assignment, and the corresponding loaded network is regarded as the basic system.

2. For the unassignable zonal interchanges, the procedure is repeated with a higher traveling quality accompanied by lower impedance factors on the various sections of the system. This process may result in the detection of routes that have not been accepted in the basic assignment and in the subsequent allocation of trip interchanges to these routes.

3. The loads obtained from the second assignment are compared with the "unused service volumes" on the basic system. "Unused service volumes" refer to the differences between the service volumes on the links and the trips assigned to these links. Assignable trip interchanges from step 2 may be allocated to the routes of the basic system as long as the service volumes on these links are not exceeded.

4. The zonal deficiencies obtained from the basic assignment are reduced by the assignable trips that are determined in step 3.

Determination of Acceptable Routes

The Simplified Proportional Assignment Technique is based on the premise that drivers select from one or more acceptable routes in their movements between specific origin-destination combinations. Unless alternate acceptable routes are properly identified, it is not possible to devise meaningful and reliable techniques of proportioning trip interchanges among the available corridors of travel. The use of SPAT in conjunction with large complex networks necessitates the determination of alternate routes in a systematic and efficient way.

Alternate route determination in this method of system evaluation refers to the selection of distinct corridors of travel within the study area. A minor difference between two paths does not justify the consideration of these routes as separate corridors for traffic movement. From the standpoint of transportation planning, corridors of travel desires describe adequately the channels of traffic flow.

If distinct routes of travel are to be developed for selected zonal interchanges, considerable portions of their lengths should represent separate travel corridors. These routes may share only limited segments of the street system. The location where these routes may share common links are in the vicinity of the terminals of the trip and over certain control sections in the transportation system. These control sections include tunnels and bridges which afford the only access between various districts in the study area.

Based on the above features of the corridors of travel, the determination of acceptable routes between zonal pairs is accomplished in the following manner.

1. The minimum-time path joining a chosen pair of zonal centroids is determined by an appropriate algorithm.

2. If this minimum-time path satisfies the pre-set level of service restriction, a central percentage of this path is removed from the network description. Only control sections on the route, such as bridges and tunnels, are exceptions to this rule.

3. The minimum-time algorithm is again employed to find the second best route for the reduced network, and the travel time on this route is compared with the pre-set service level.

4. A central percent amount of this second best route is now removed from the network description if this routing is acceptable according to the level of service criteria.

5. The process of minimum-time path search and the removal of the central section of the determined route is repeated until the minimum-time route over a particular network description does not fulfill the service level requirements. The final set of acceptable routes comprises all possible corridors of travel that accommodate traffic between the prescribed zones at the established level of service.

This logic procedure establishes the framework for the development of a computer program to obtain acceptable routes over a network. Detouring around individual links is avoided in the choice of the second, third or n-th best route by removing a certain percentage of the links which comprise the route in each previous determination. The removal of some links of an acceptable route from a network description sets a limit on the percent overlap between this route and other corridors of travel. The appropriate percent overlap between two acceptable routings was developed in the section entitled "Method of Route Determination" of the sensitivity analysis.

Proportioning Trips Among Alternate Routes

When several acceptable routes exist between an origin-destination pair of zones, the zonal interchanges are proportioned among these available travel routes. The basis of proportionality is predicated on the relative attractiveness of these routes. Measures of route attractiveness may be afforded by one or more descriptive variables.

Parameters that have been used to proportion traffic to alternate routes include time, distance and cost. The California diversion curves, which are based on time and distance, provide the same emphasis to these parameters on arterial streets with average speeds of 30 mph. The Detroit study used distance ratio and speed ratio to define the basis for proportioning traffic between alternate routes. The cost of a trip is relatively insensitive in the choice of routes because drivers possess little knowledge on the estimation of total travel costs (20). Instead, the factor of driver stress is introduced as a parameter to explain the drivers' attitudes toward alternate route selection (26).

Differences which exist among drivers in the selection of routes appear to be related to the great importance of direct and quick access to the destination in the work trip and to the increasing importance of amenities, such as comfort and pleasant scenery, in social-recreational travel (42). This finding leads to the conclusion that a route is chosen on the basis of the following factors for a particular trip purpose.

1. Travel time.
2. Trip distance.
3. Driving comfort.

The purpose of a trip and the characteristics of the drivers determine to a large degree the relative weights of these three factors in proportioning trips among alternate routes.

Driving comfort is closely related to the nature of the facilities that are used for a particular trip. High-type facilities provide good driving qualities and induce little tension on the drivers under stable flow conditions. The tension experienced on a route is greatly affected by the traffic interferences. These interferences include signalized intersections, parking maneuvers and access to adjacent property. Before a transportation system is used in traffic assignment processes, the various components of the street network are described as links. A link is a street section defined by two numbered points at each end called nodes. These nodes are incorporated in the network description at intersections of network streets and at points of access to abutting property. Because nodes represent locations of interference, the number of nodes on a route may be related to the tension experienced by the drivers on that route. A limited-access facility, which enhances driving comfort and enjoyment, generally has fewer number of nodes than an arterial street with numerous signalized intersections and access points.

The proposed procedure for proportioning traffic among several acceptable routes includes the following sequence of operations.

1. An attractiveness index is calculated for each acceptable route according to the following equation.

$$F_i = \frac{1}{T_i^{\,a}} \times \frac{1}{D_i^{\,b}} \times \frac{1}{N_i^{\,c}}$$

where F_i = attractiveness index of route "i".

T_i = travel time on route "i".

D_i = total distance on route "i".

N_i = number of nodes on route "i".

a = exponent of travel time.

b = exponent of total distance.

c = exponent of the number of nodes.

2. The trips to be assigned to each route are obtained from the following relationship.

$$L_i = L \times \frac{F_i}{F_1 + F_2 + \ldots\ldots F_n}$$

where L_i = trips assigned to route "i".

L = total distributed trips to be assigned to the alternate routes.

n = number of acceptable routes.

The values for the exponents a, b and c are dependent on the trip purposes. A sensitivity analysis was performed on the proportionality factor for varying values of the exponents of travel time, total distance and number of nodes. The resulting attractiveness indices varied only by 5 to 10 percent for various combinations of exponent values ranging from the square root to the second power.

Further research in the area of driver behavior is needed to quantify these variables. For the purpose of demonstrating the application of the new concept, the value of 1.0 was assigned to these three variables in the succeeding applications of the Simplified Proportional Assignment Technique.

Programming of the Simplified Proportional Assignment Technique

The development of a computer program for the application of the Simplified Proportional Assignment Technique is included in this work. A flow diagram of the system evaluation logic is shown in Figure 10, and a complete computer program of the assignment procedure is included as Appendix B. The algorithm used in the minimum-time path search is an extension of the one developed by the Road Research Laboratory (21). The final computer program is written in FORTRAN IV and is designed to demonstrate system evaluation by the Simplified Proportional Assignment Technique. Refinements in the computer programming could be accomplished to make the technique more efficient when large transportation systems are evaluated.

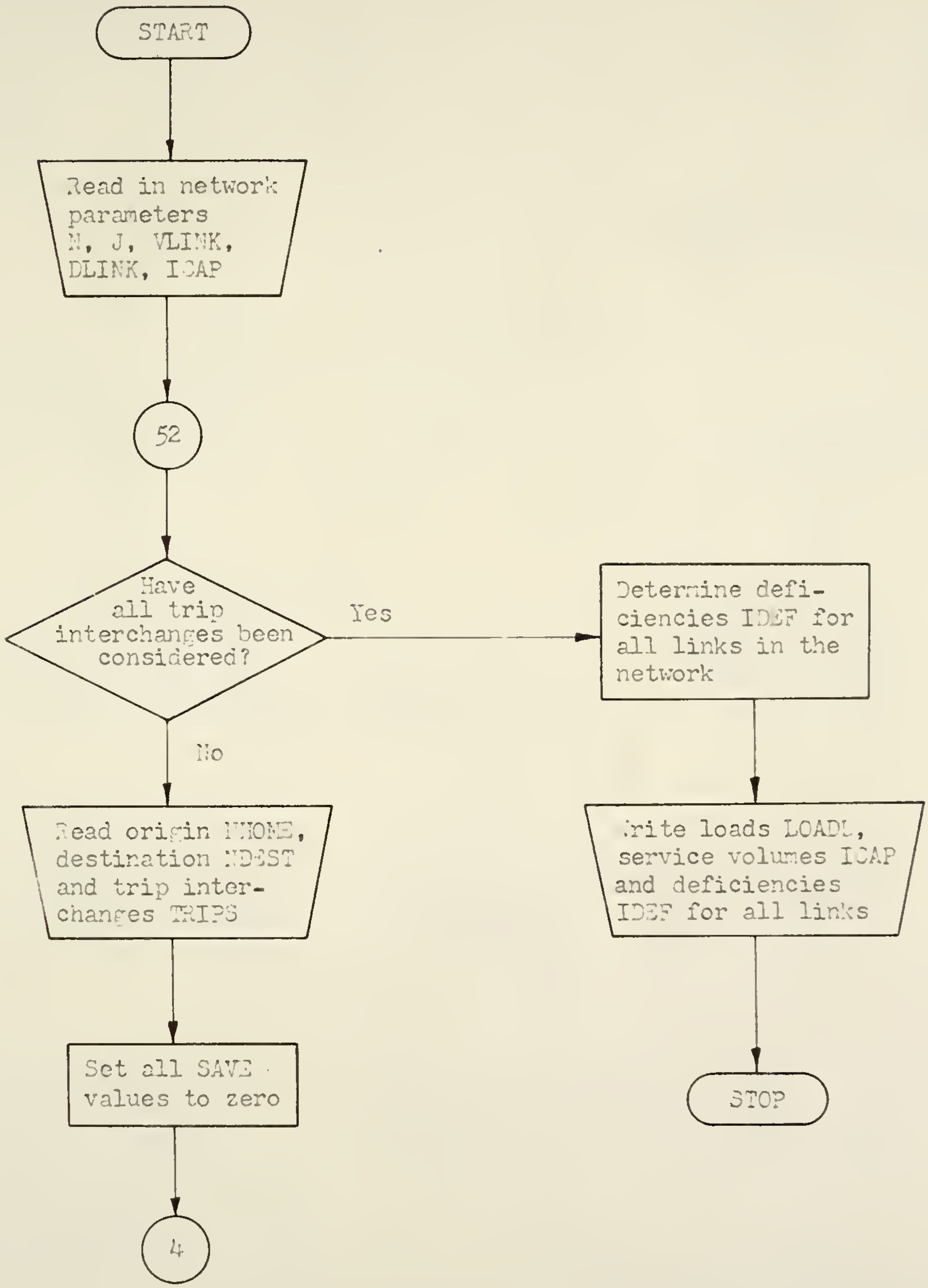

Fig. 10 Flow Diagram for the Simplified Proportional Assignment Technique

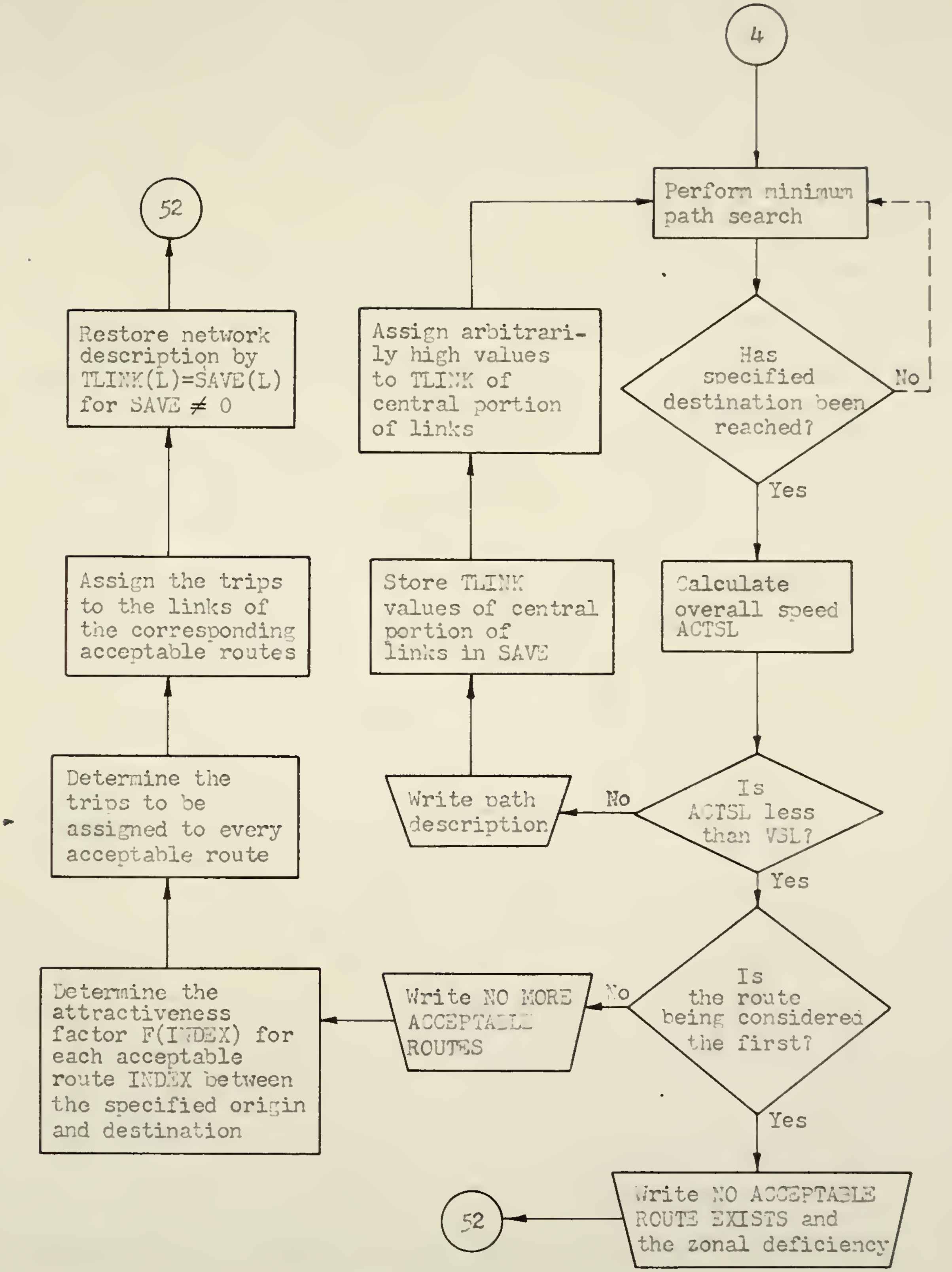

Fig. 10 (continued)

SENSITIVITY ANALYSIS

The Simplified Proportional Assignment Technique includes the determination of alternate acceptable routes and the subsequent allocation of trip interchanges to these routes. The outcome of the assignment procedure depends to a great extent on the nature and the number of acceptable routes. In the following sections, the acceptable paths are evaluated with respect to the method of route selection and the various limitations on the number of adopted paths. The analyses of the resulting corridors of travel establish the best procedure for obtaining the proper number of acceptable routes in SPAT.

The effects of decision-making parameters, such as the levels of service, on the evaluation of a transportation plan are also demonstrated in subsequent sections. Interzonal service levels and qualities of traffic flow were varied over practical ranges and the adequacy of a plan was tested in accordance with these variations.

Route Evaluation

The proposed method for the determination of acceptable routes by SPAT was evaluated by considering the street network of Indianapolis, Indiana. The data for the network description had been collected by the study group of the Indianapolis Regional Transportation and Development Study (IRTADS). Travel speeds on the various links of the network represent the average of two mid-day and one peak-hour space-mean speeds.

A sample of seven origin-destination combinations was utilized in the evaluation of acceptable routes. These zonal interchanges constitute a wide spectrum in trip length and location within the urban area to provide a representative sample of urban travel conditions. Trip lengths vary between one and ten miles, and zonal transfer locations range from inter-core movements to trips made wholly on the outskirts of the city. The randomly selected zonal centroids, which serve as terminal points for the evaluated routes, are shown in Figure 11.

Because alternate acceptable routes represent distinct corridors of travel, only portions of their lengths share common links. The properties of the determined routes were analyzed first in relation to the permissible overlap between two or more alternate routes. After the percentage of overlap was determined for the best corridor representation, the selection of the feasible number of routes for inclusion in the assignment procedure was investigated.

Method of Route Determination

The overlap restriction between two acceptable routes is specified as a percentage of the total trip length. This constraint can be transformed into a percentage of the total links on a route by assuming that route lengths are approximately proportional to the number of links on a route. In the initial analysis of acceptable paths, the terminal overlaps between alternate routes were set at 0, 5, 10, 15 and 20 percent of the total route lengths. The optimum overlap

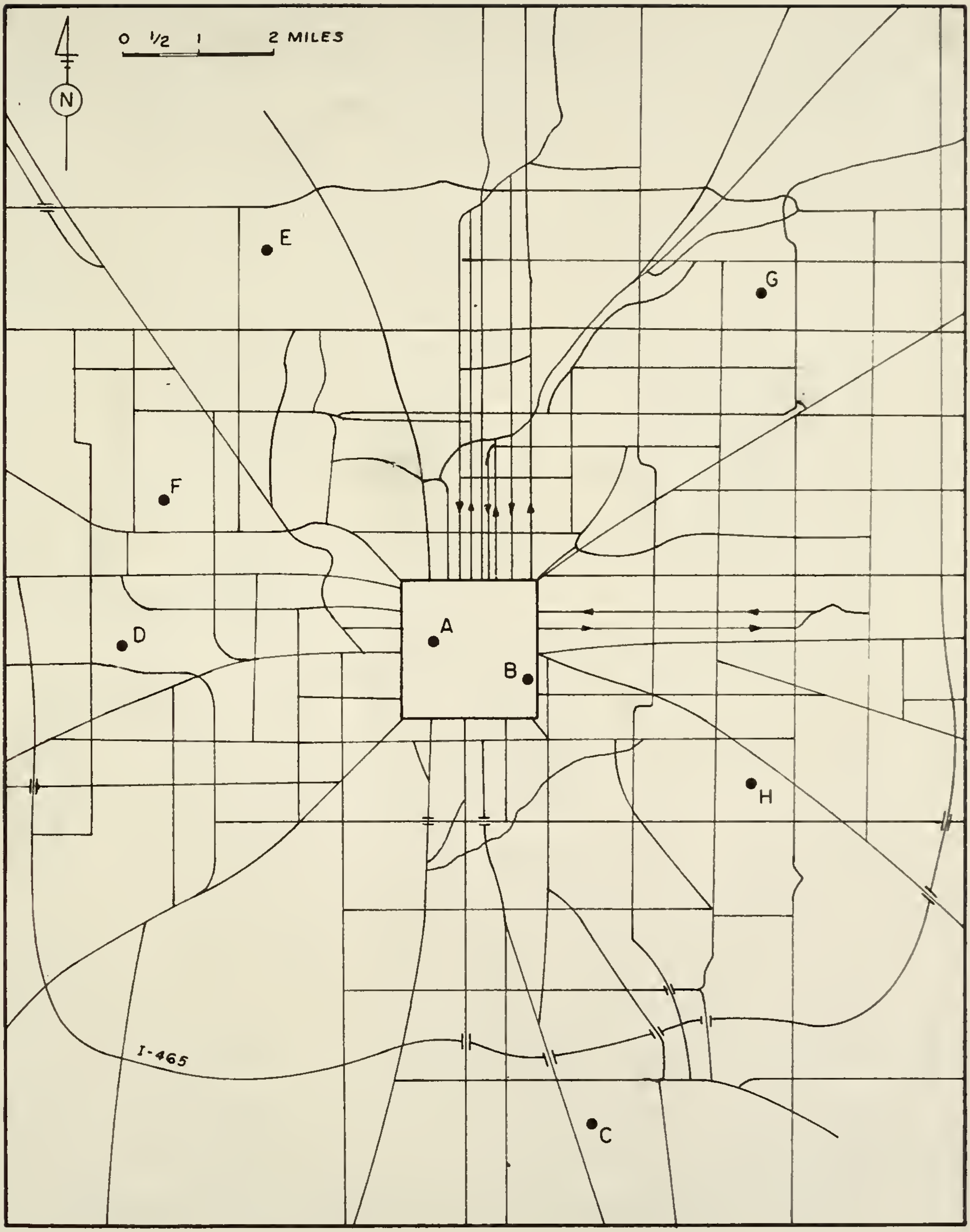

Fig. 11 Location of the Evaluation Zones
Indianapolis, Ind.

restriction was between 0 and 10 percent of the total trip length. Two further overlap values of [illegible] and 7 percent were then incorporated in the analysis for a finer convergence on the best overlap specification.

The acceptable level of service was established at a sufficiently low value to permit the inclusion of all routes that should be considered in the analysis. A service level of 15 mph was selected for travel between all zonal combinations in this phase of the investigation. The overall speeds were above 18 mph on the determined acceptable routes. Because the best non-acceptable routes did not provide an overall average speed higher than 1[illegible] mph, the selected level of service could have been set at any value between 2 and 1[illegible] mph without having any influence on the obtained results.

The number of available routes for the seven zonal combinations and percent of route overlap are presented in Table 2. Some zonal combinations have as many as 20 different routings. Although every determined route satisfied the overall speed restriction, a number of these routes described trips much longer than the best available path both in travel time and total distance. To limit the analysis to realistic routings only, a restriction was placed on the number of analyzed routes. The termination point in route selection was arbitrarily established for that routing with both travel time and distance exceeding twice the respective values for the best available route. The resulting reduction in the number of acceptable routes from the total routes available for the specified service level is shown in Table 2.

TABLE 2

Number of Available Routes for Various Zonal Combinations and Percent of Route Overlap

Zonal Combination		1		2		3		4		5		6		7	
Trip Ends		[illegible] - A		D - F		E - F		[illegible] - C		H - G		H - C		H - F	
Length of Best Route (mi)		1.4		2.9		5.4		5.7		6.5		6.8		9.2	
		Total	Red.	Total	Red.	Total	Red.	Total	Red.	Total	Red.	Total	Red.	Total	Red.
Percent Overlap	0	5	3	4	3	3	3	3	3	4	4	3	3	4	4
	3	5	3	4	3	3	3	3	3	4	4	3	3	7	6
	5	7	3	5	3	4	3	3	3	9	6	3	3	7	6
	7	7	3	5	3	4	3	3	3	10	6	3	3	8	7
	10	11	4	6	3	4	3	5	5	11	7	3	3	10	9
	15	16	6	7	3	5	3	13	8	11	7	5	5	14	12
	20	20	7	8	3	9	5	16	9	11	9	11	8	16	15

Red. = Reduced

The acceptable paths were traced according to the established procedure, and the characteristics of these routes analyzed as to their number and location. Samples of these routes are shown in Figures 12 through 25. The following observations were made in regard to various characteristics of the selected paths.

1. Small percentages of permissible route overlap result in unrealistic detouring in the vicinity of trip terminals. Because of this critical overlap restriction, a search for alternate routes is forced to seek circuitous ways to leave an origin and/or to reach a destination.

2. High percentages of route overlap produce little distinction between two acceptable paths. Overlaps which exceed 15 percent of the total lengths of the routes tend to preclude the attainment of distinct corridors of travel.

3. Little change occurs in the nature of the determined routes over the range of [illegible] to 10 percent of the percentage of overlap at either end of a routing.

Because the selection of different overlap restrictions resulted in various sets of acceptable routes, these sets of routes were rated for every zonal combination by assigning to them the utility values listed in Table 3. The ratings are subjective evaluations of the extent to which the determined routes represent distinct corridors of travel. The utility values range from 1.0 for the least desirable to 7.0 for the best representation of these travel corridors. After the utility values were determined for every zonal combination, the cumulative utilities were obtained by summing the values over all

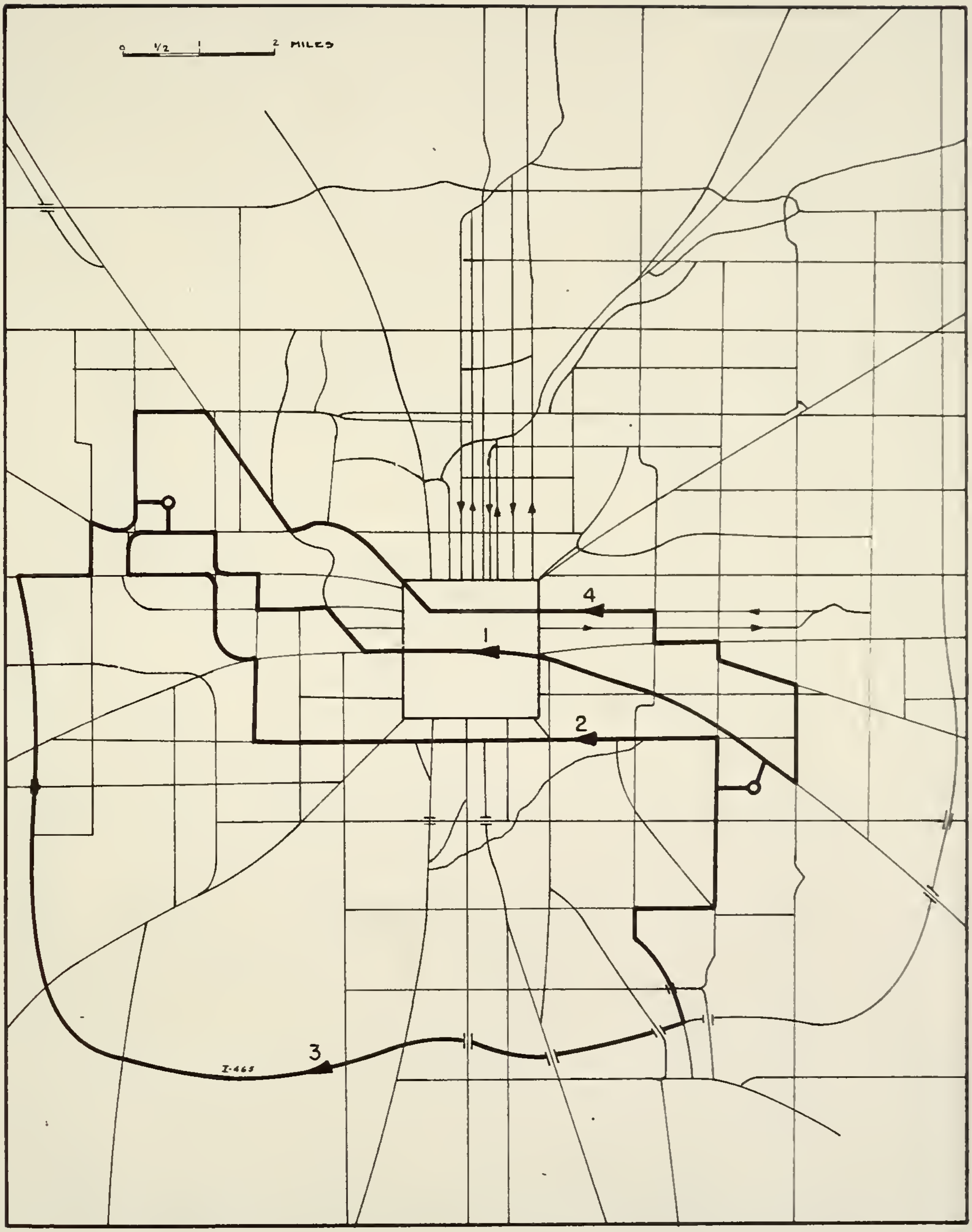

Fig. 12 Acceptable Routes for Zonal Combination 7
Overlap = 0%

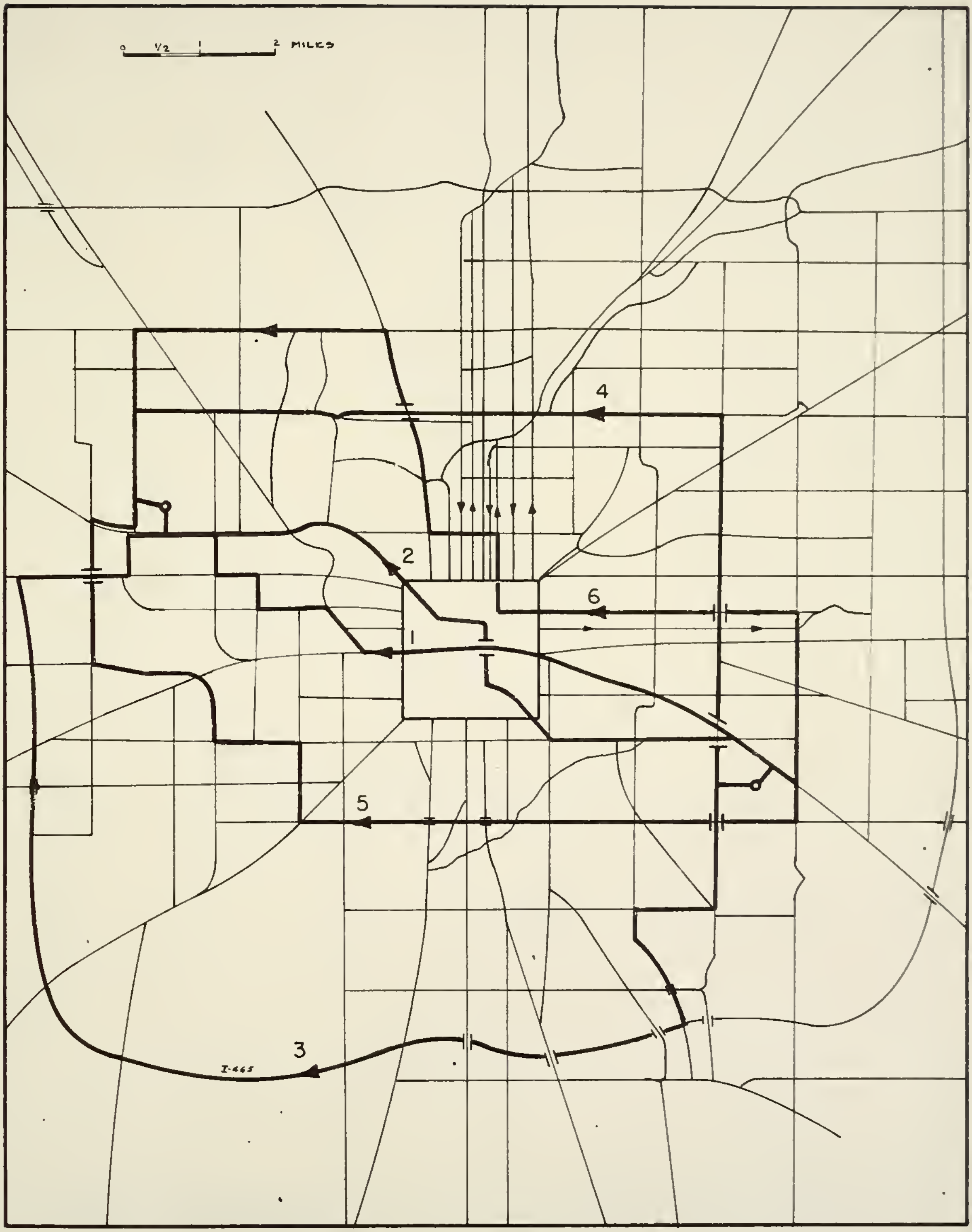

Fig. 13 Acceptable Routes for Zonal Combination 7
Overlap = 3%

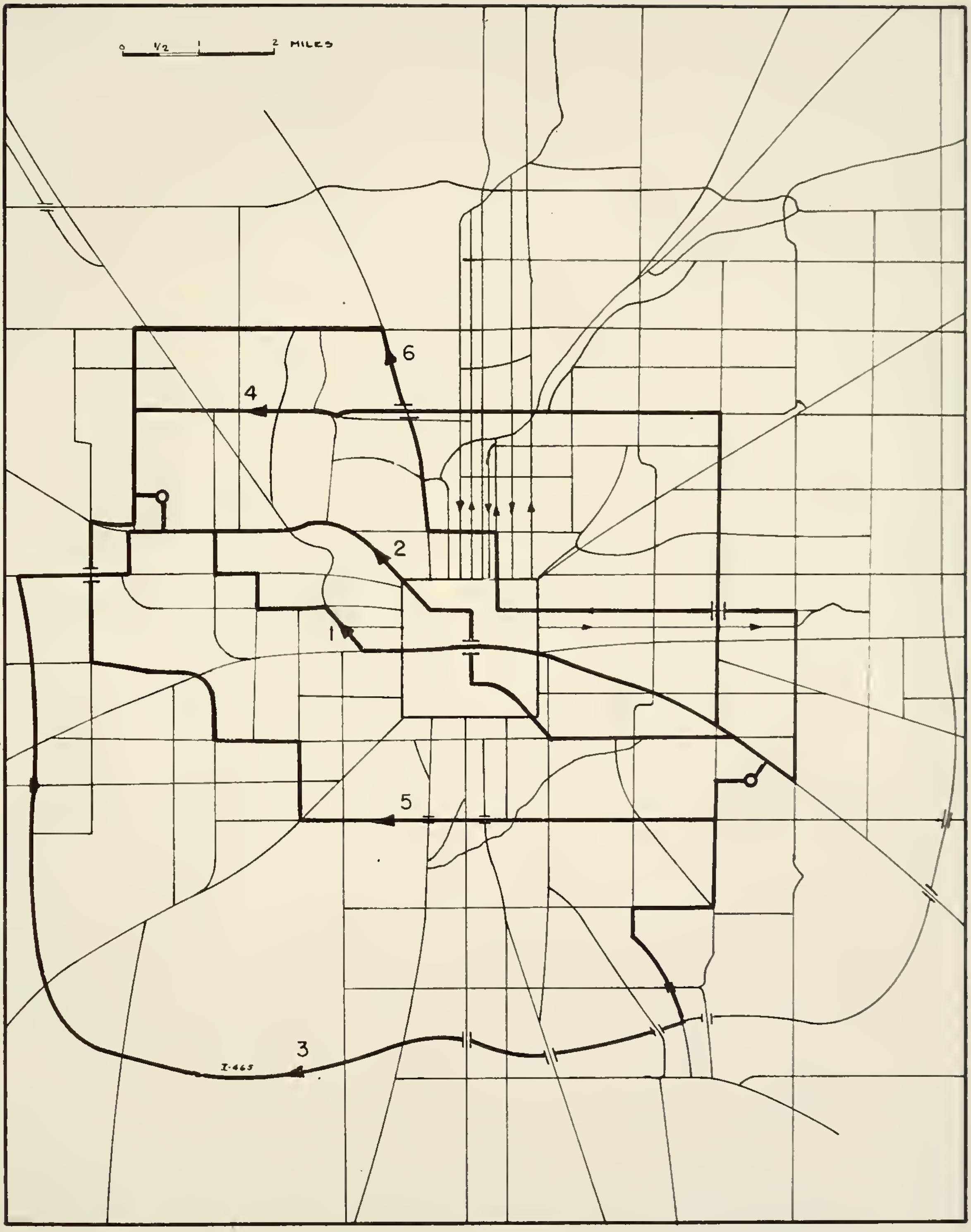

Fig. 14 Acceptable Routes for Zonal Combination 7
Overlap = 5%

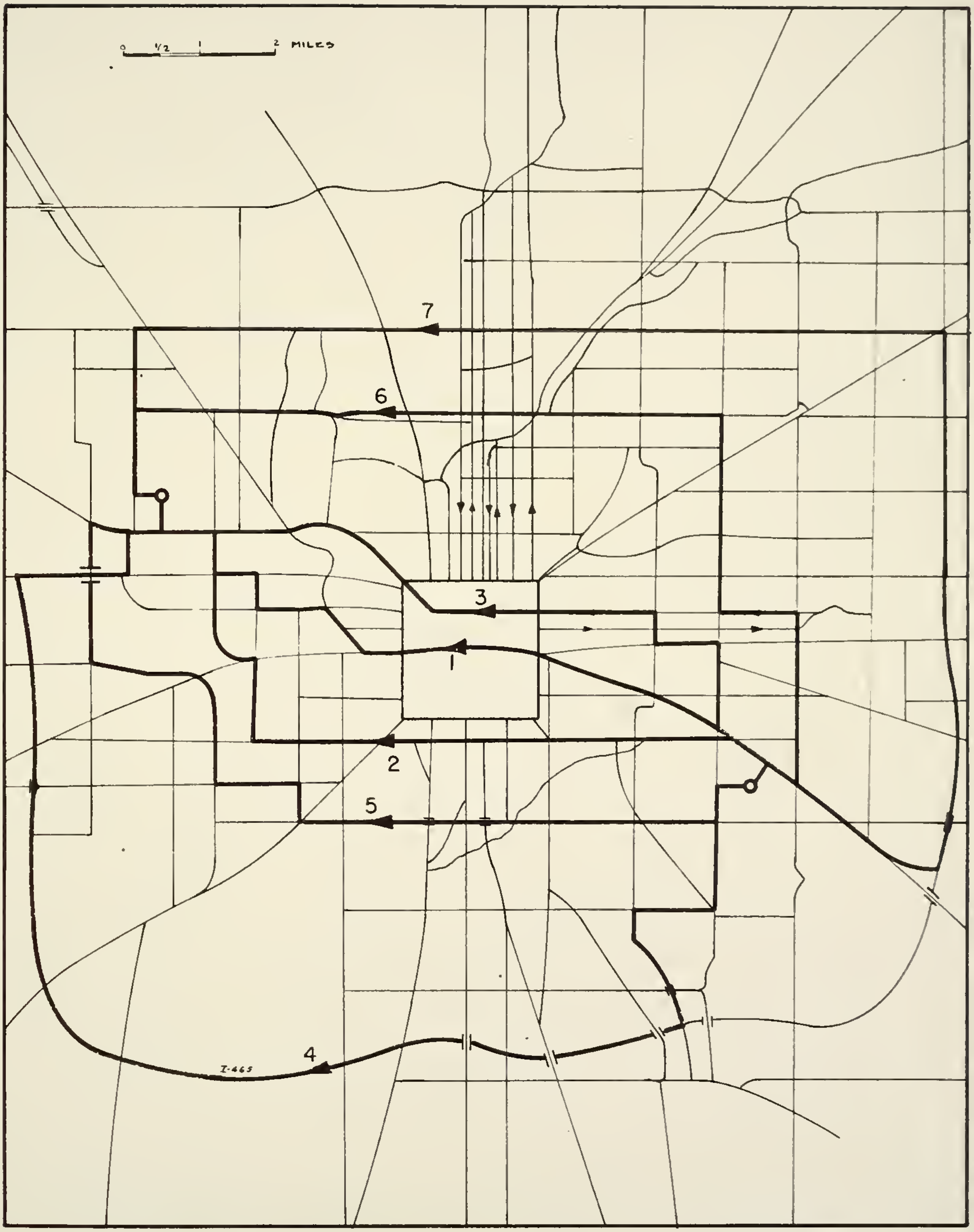

Fig. 15 Acceptable Routes for Zonal Combination 7
Overlap = 7%

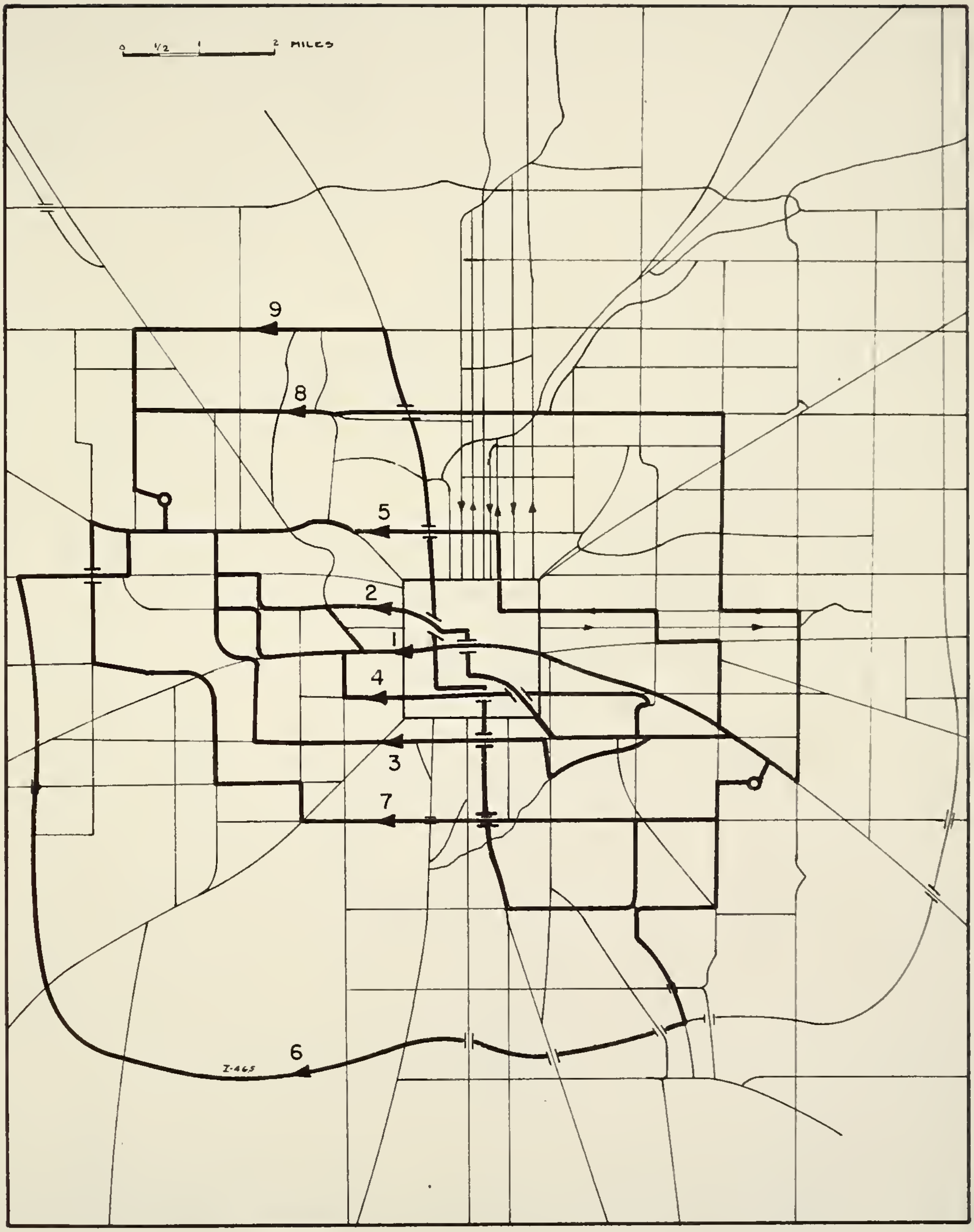

Fig. 16 Acceptable Routes for Zonal Combination 7
Overlap = 10%

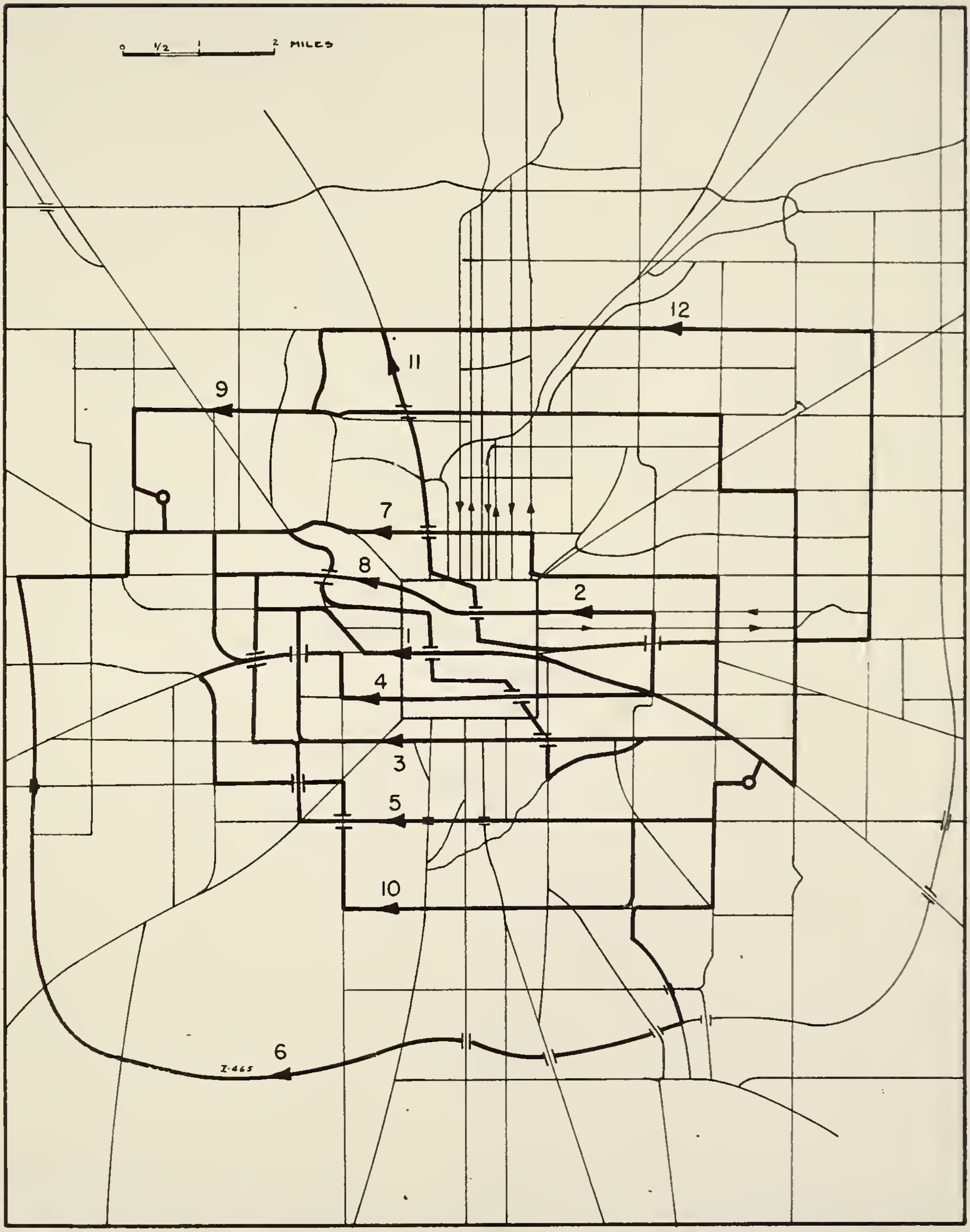

Fig. 17 Acceptable Routes for Zonal Combination 7
Overlap = 15%

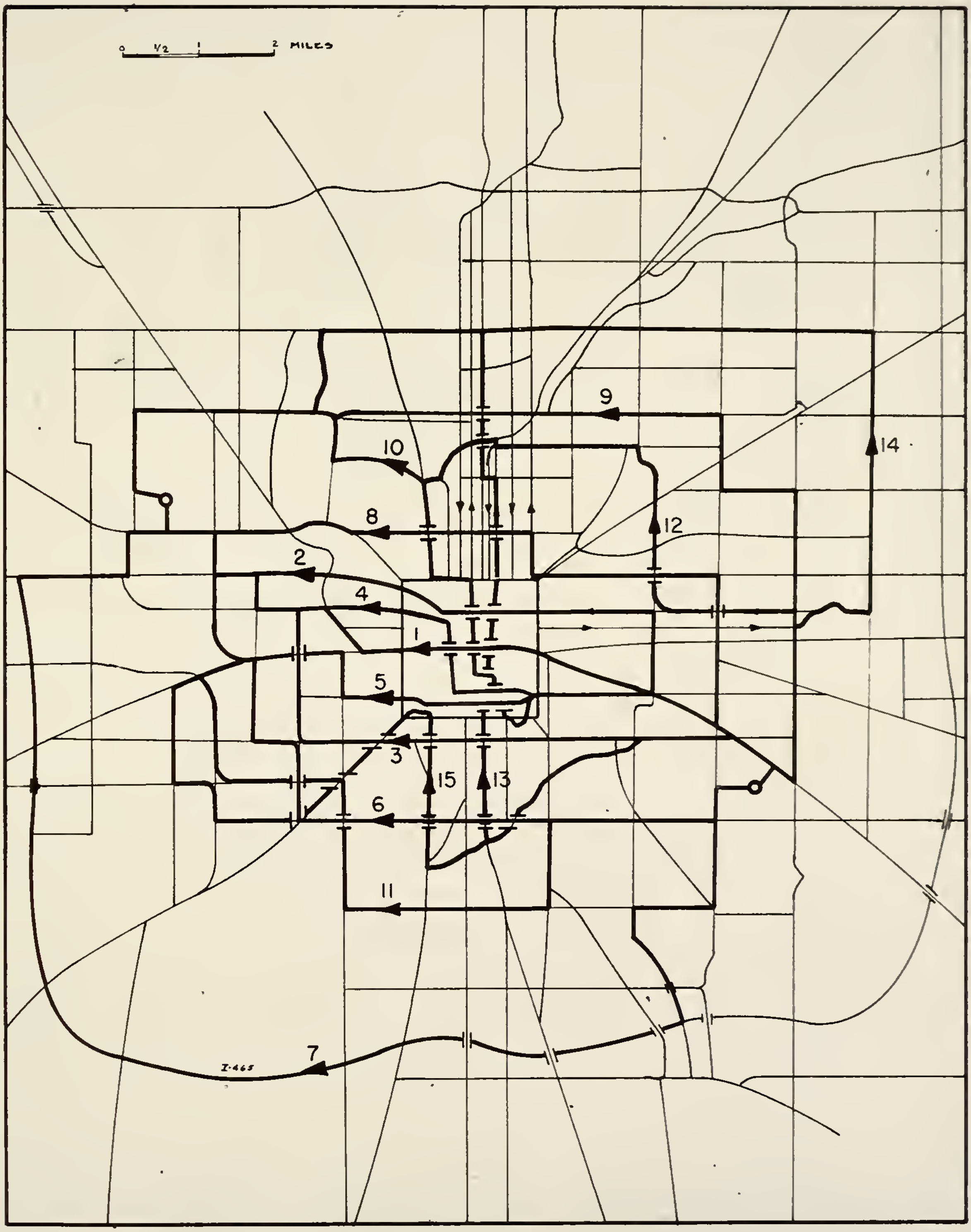

Fig. 18 Acceptable Routes for Zonal Combination 7
Overlap = 20%

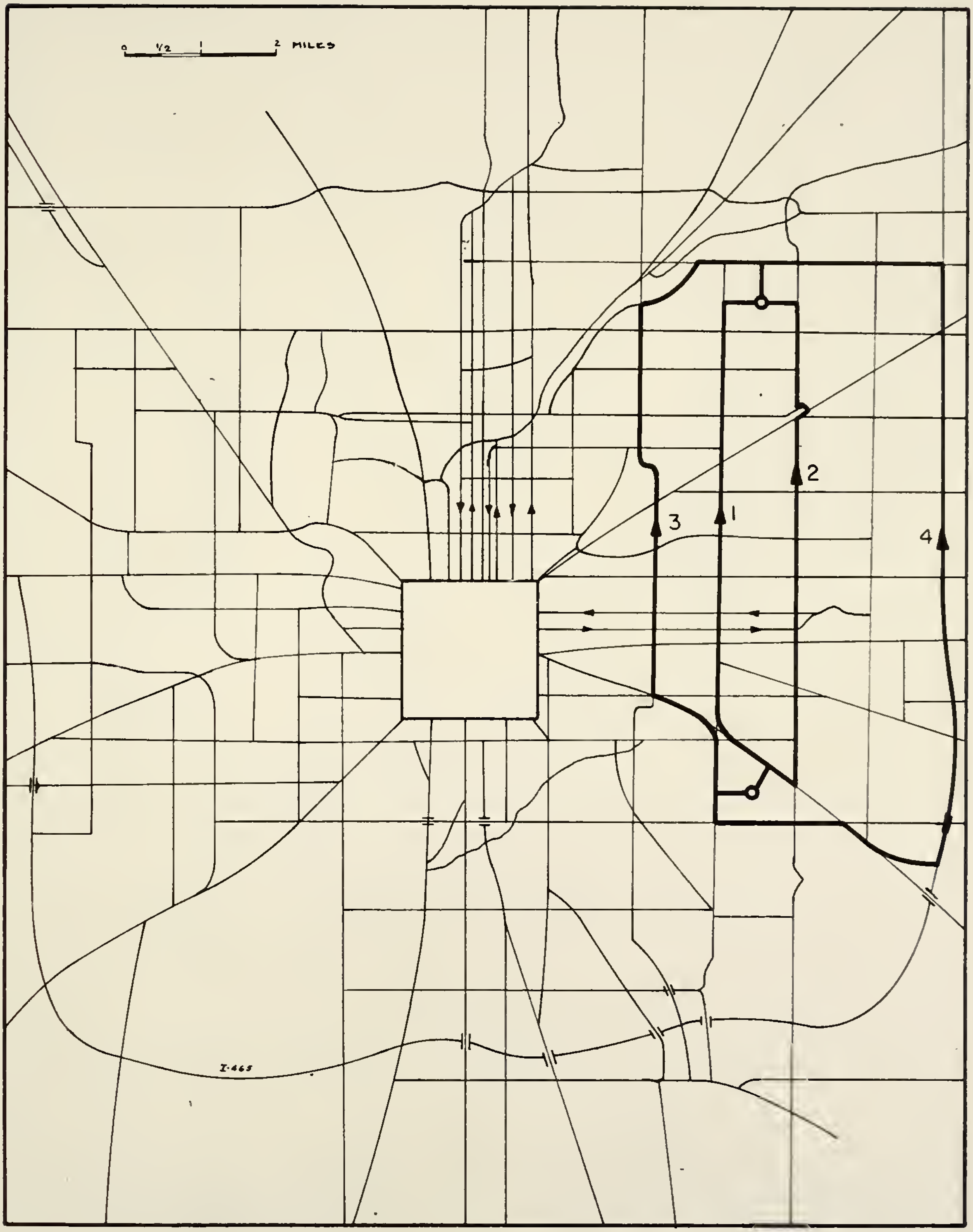

Fig. 19 Acceptable Routes for Zonal Combination 5
Overlap = 0%

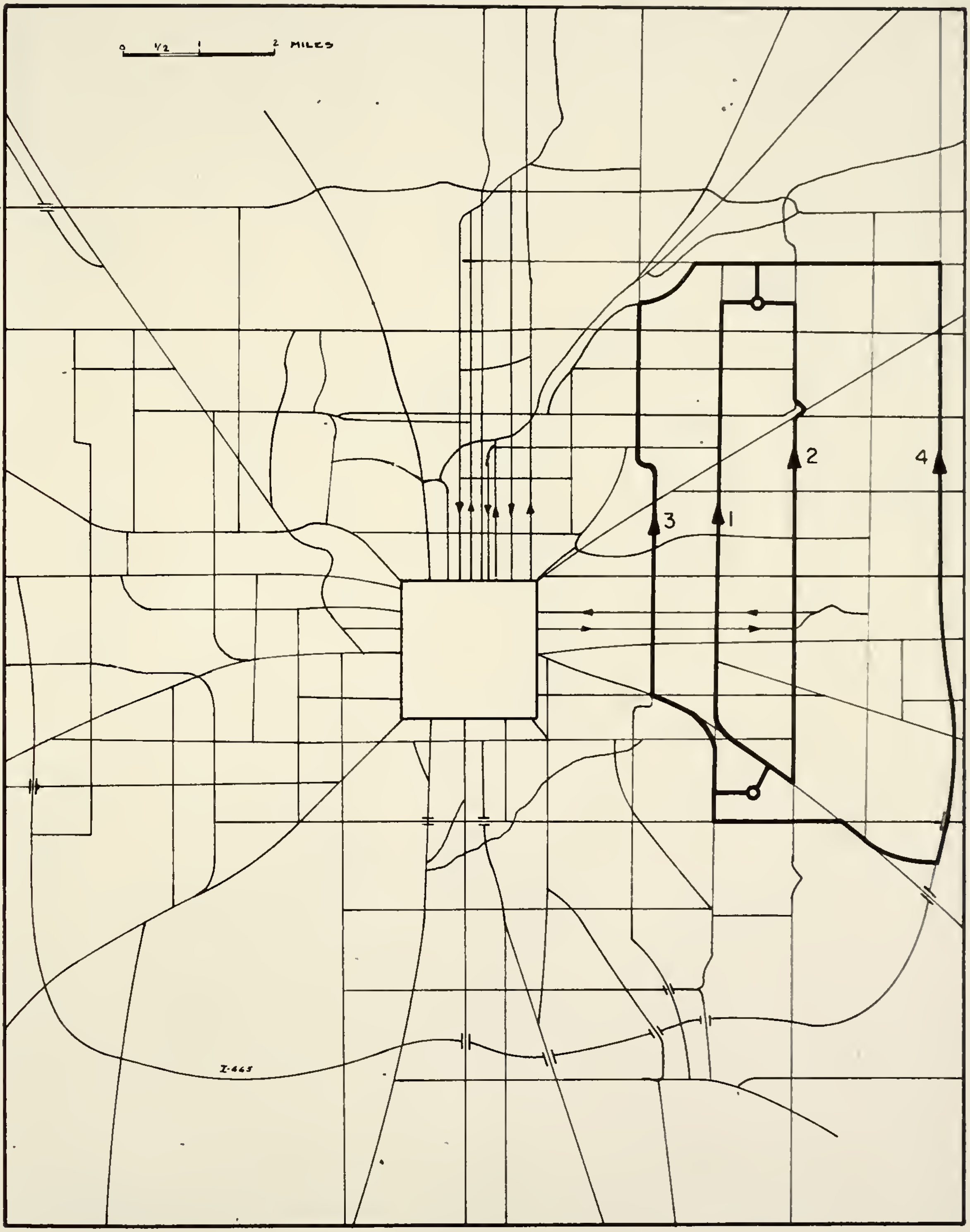

Fig. 20 Acceptable Routes for Zonal Combination 5
Overlap = 3%

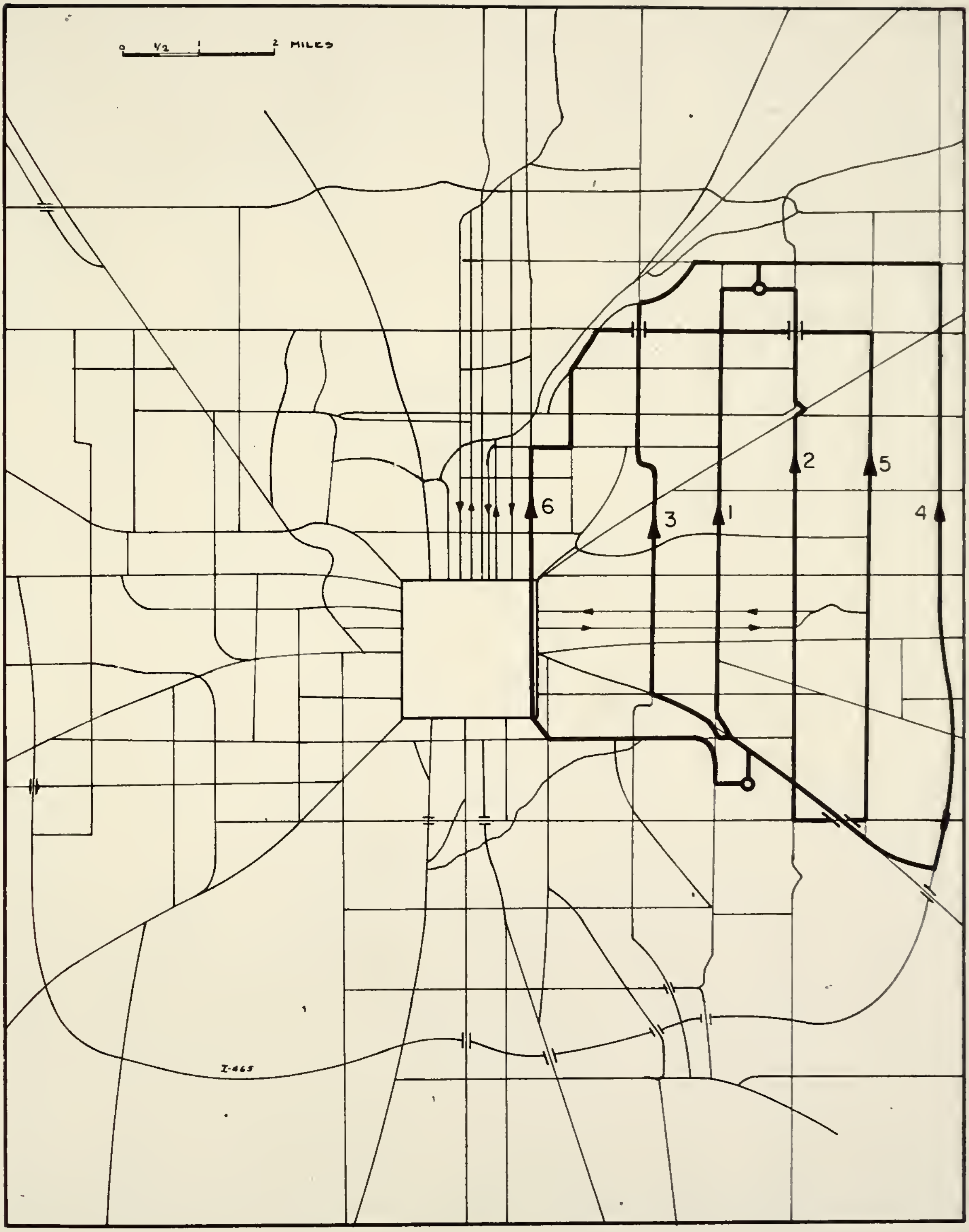

Fig. 21 Acceptable Routes for Zonal Combination 5
Overlap = 5%

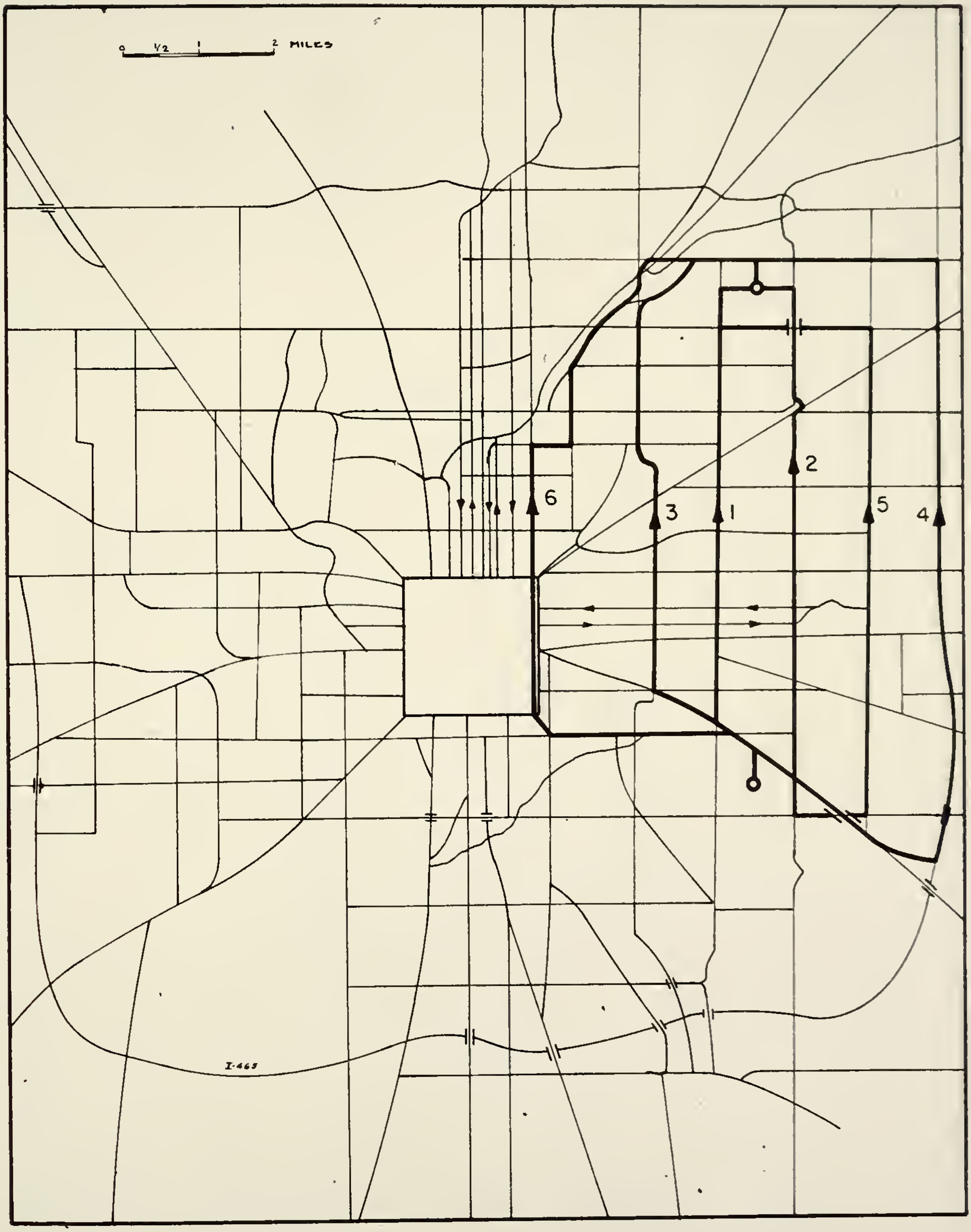

Fig. 22. Acceptable Routes for Zonal Combination 5
Overlap = 7%

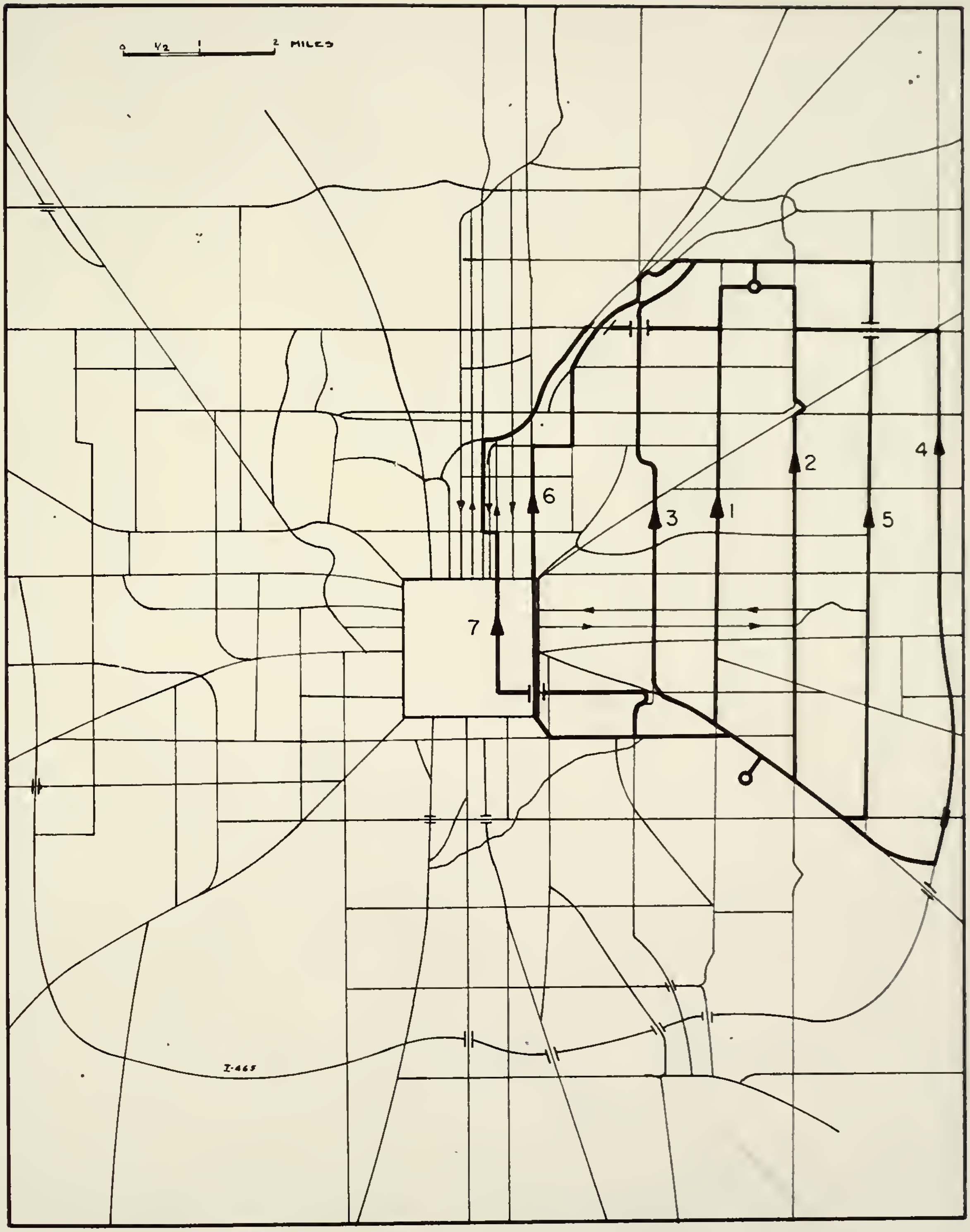

Fig. 23 Acceptable Routes for Zonal Combination 5
Overlap = 10%

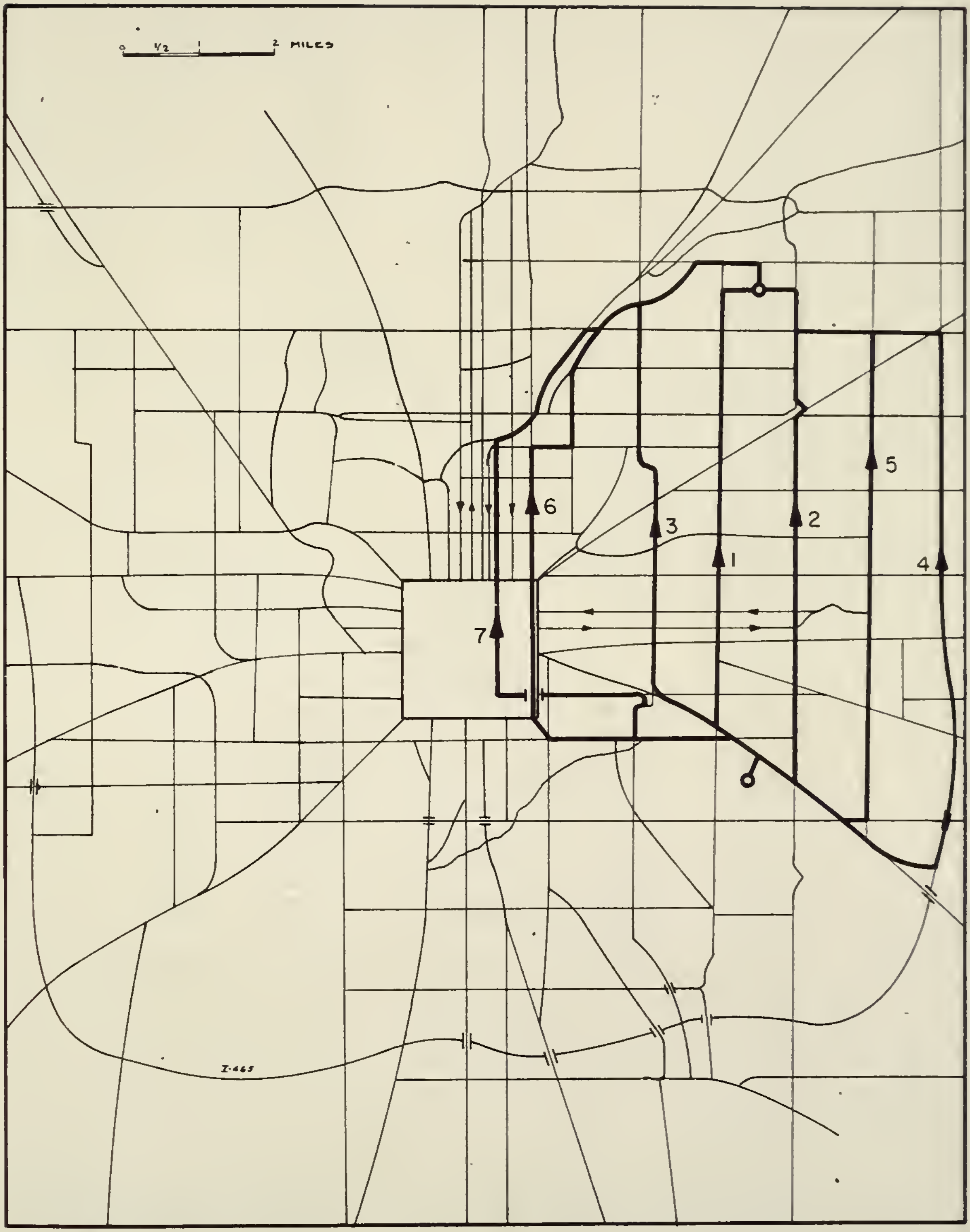

Fig. 24 Acceptable Routes for Zonal Combination 5
Overlap = 15%

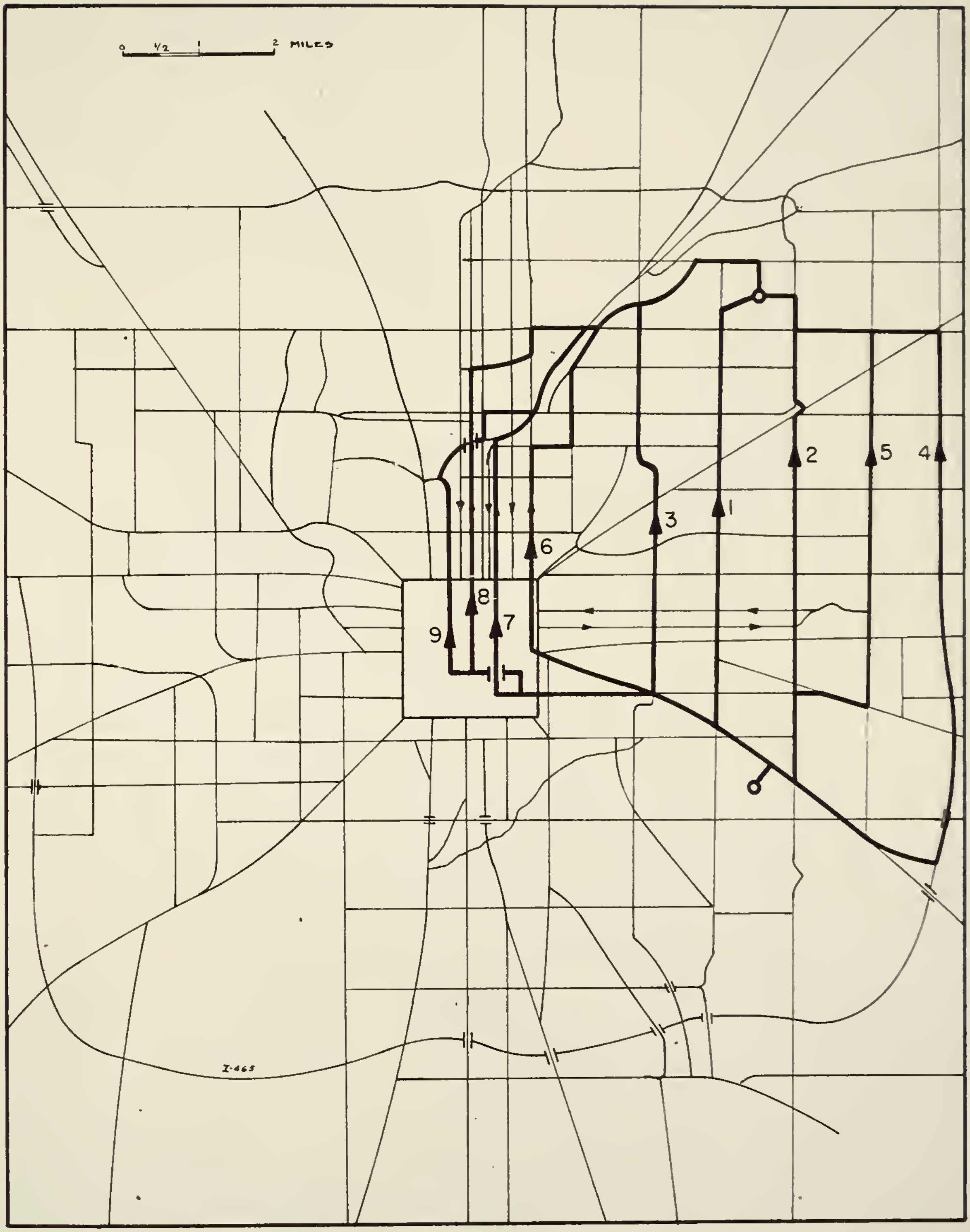

Fig. 25 Acceptable Routes for Zonal Combination 5
Overlap = 20%

TABLE 8

Quality Ratings for the Acceptable Routes

Zonal Combinations		1	2	[illegible]	4	5	6	7	Sum of Utilities	Rank Score
Trip Ends		[illegible] - A	D - F	E - F	[illegible] - C	H - G	H - [illegible]	H - F		
Length of Best Route (mi)		1.4	2.9	5.4	5.7	6.5	6.8	9.2		
Percent Overlap	0	4.0	4.0	.0	5.5	2.0	4.0	.0	25.5	5
	3	4.0	4.0	.0	5.5	2.0	4.0	5.0	27.5	4
	5	4.0	4.0	.0	5.5	4.0	4.0	6.0	.0.5	3
	7	7.0	4.0	7.0	5.5	5.0	6.5	7.0	42.0	1
	10	6.0	4.0	5.5	.0	6.0	6.5	4.0	5.0	2
	15	1.5	4.0	5.5	2.0	7.0	2.0	2.0	24.0	6
	20	1.5	4.0	1.0	1.0	2.0	1.0	1.0	11.5	7

zonal combinations. A rank score was then assigned to each cumulative utility value. A 7-percent permissible overlap at either end of alternate routes provided the closest attainment of realistic corridors of travel. The second and third best criteria specify a 10 and 5 percent overlap respectively.

Number of Acceptable Routes

When the overall speed is used as the only criterion for selecting a route, the set of acceptable paths may include excessively long routings. Although the proposed proportional assignment technique assigns very little traffic to exceedingly long routes, the inclusion of these paths in the assignment process reduces the efficiency of the technique unnecessarily. In addition to satisfying specific overall speeds, acceptable routings should meet limitations pertaining to the actual number of paths considered in the assignment process for any zonal interchange.

Conditions that may be specified to limit the number of acceptable routes include the following restrictions.

1. Upper limit on travel time.
2. Upper limit on total distance.
3. Upper limit on both travel time and total distance.
4. Upper limit on number of routes.

The upper limits placed on travel time and/or total distance are related to the values of these parameters on the first "best" route. The limits that were chosen for this analysis include 1.25, 1.50, 1.75 and 2.0 times the corresponding values on the "best" available route.

The numbers of acceptable routes resulting from the proposed limiting conditions are shown in Table 4 for the seven combinations of zonal interchanges.

A subjective rank score was assigned to the number of acceptable routes associated with each set of limiting conditions. This evaluation was based on the exclusion of attractive travel corridors and the acceptance of unrealistic paths. The limiting conditions for each set of restrictions were then compared to determine the proper number of acceptable routes to include in the proportional assignment.

The establishment of an upper limit on total distance produced the same number of acceptable routes as that resulting from an upper limit on both travel time and total distance. Although either restriction may be selected to define a limit on the number of acceptable routes, the use of both the travel time and the total distance restrictions is recommended to guard against inconsistency in the description of impedances on network links. In addition to satisfying the overall speed restrictions, the acceptable routes in SPAT must provide travel times and route lengths that do not exceed 1.75 of the corresponding values on the initial minimum-time path.

When the suggested restriction is imposed on the selection of the maximum number of acceptable routes, six of the seven zonal combinations have three acceptable routes. A fixed upper limit on the number of acceptable routes is not, however, recommended because other variations in trip lengths and locations within an urban area may produce varying numbers of acceptable routes. That is, no unique number of acceptable routes exists in the selection of travel corridors.

TABLE 4

Number of Acceptable Routes for Various Limiting Conditions on Route Selection

Limiting Conditions		Zonal Combination							Rank Score within Group *	Rank Score among Groups **
		1	2	3	4	5	6	7		
No Restriction		7	5	4	3	10	3	8		5
Upper Limit on Time	1.25	1	2	1	2	2	3	3	3	
	1.50	2	3	1	3	4	3	6	1	3
	1.75	3	3	2	3	6	3	6	2	
	2.00	3	3	3	3	7	3	7	4	
Upper Limit on Distance	1.25	2	2	1	2	2	1	3	3	
	1.50	2	3	1	3	3	1	3	2	2
	1.75	3	3	1	3	3	3	3	1	
	2.00	3	3	3	3	6	3	7	4	
Upper Limit on Time & Dist.	1.25	1	2	1	2	2	1	3	3	
	1.50	2	3	1	3	3	1	3	2	1
	1.75	3	3	1	3	3	3	3	(1)	
	2.00	3	3	3	3	6	3	7	4	
Upper Limit on No. of Routes		3	3	3	3	3	3	3		4

*Ranking achieved by subjective evaluation.

**Ranking among groups is used on the best score within each group.

System Evaluation

The application of the Simplified Proportional Assignment Technique to the evaluation of proposed plans involves the use of decision-making variables. Those parameters whose values are selected by the planning team include the interzonal levels of service and the quality of traffic flow for a transportation network. The influence of these variables on the evaluation of a plan is demonstrated in this section.

The City of Monroe, North Carolina, was selected for measuring the sensitivity of the decision-making variables on system evaluation. The 1990 projected population is 17,000 for this community, and the general layout of the planning area is presented in Figure 26. The arrangement of few street segments was slightly altered in this analysis to obtain a clearer representation of the function of the transportation system. To obtain the various trip interchanges for use in the traffic assignment technique, the study area was divided into the origin-destination zones that are shown in Figure 27. The transportation system was coded by the link and node descriptions displayed in Figure 28.

The basic information concerning the projected trip interchanges and the nature of the transportation system were obtained from a study report prepared for the City of Monroe by the North Carolina State Highway Commission (28). Because detailed descriptions of the characteristics of the various components of the transportation network were not presented in the study report, all missing information related to the network description was assumed for this sensitivity analysis. The peak-hour trip interchanges were taken as 10 percent of the total

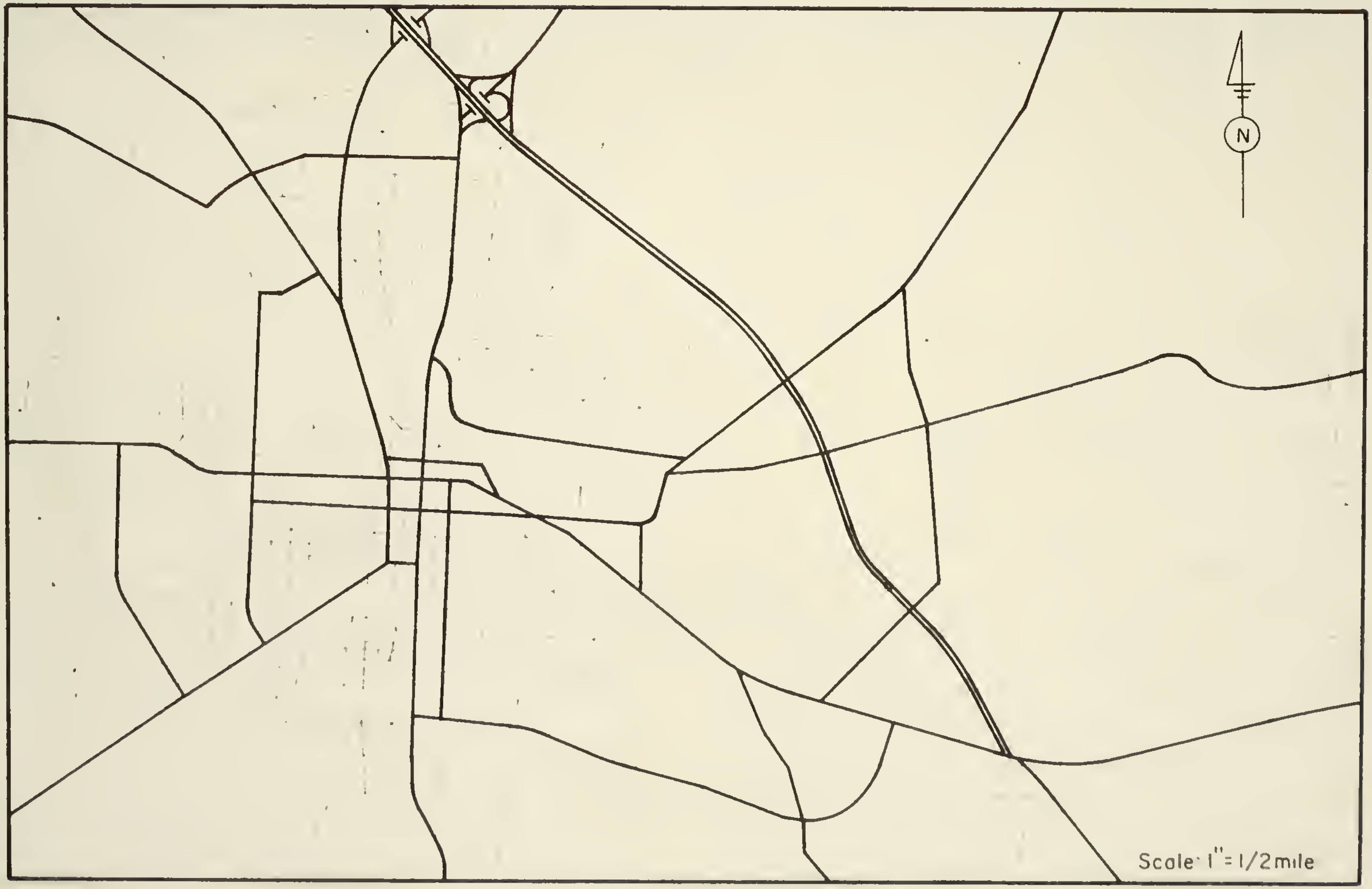

Fig. 26 General Layout
Monroe, N C

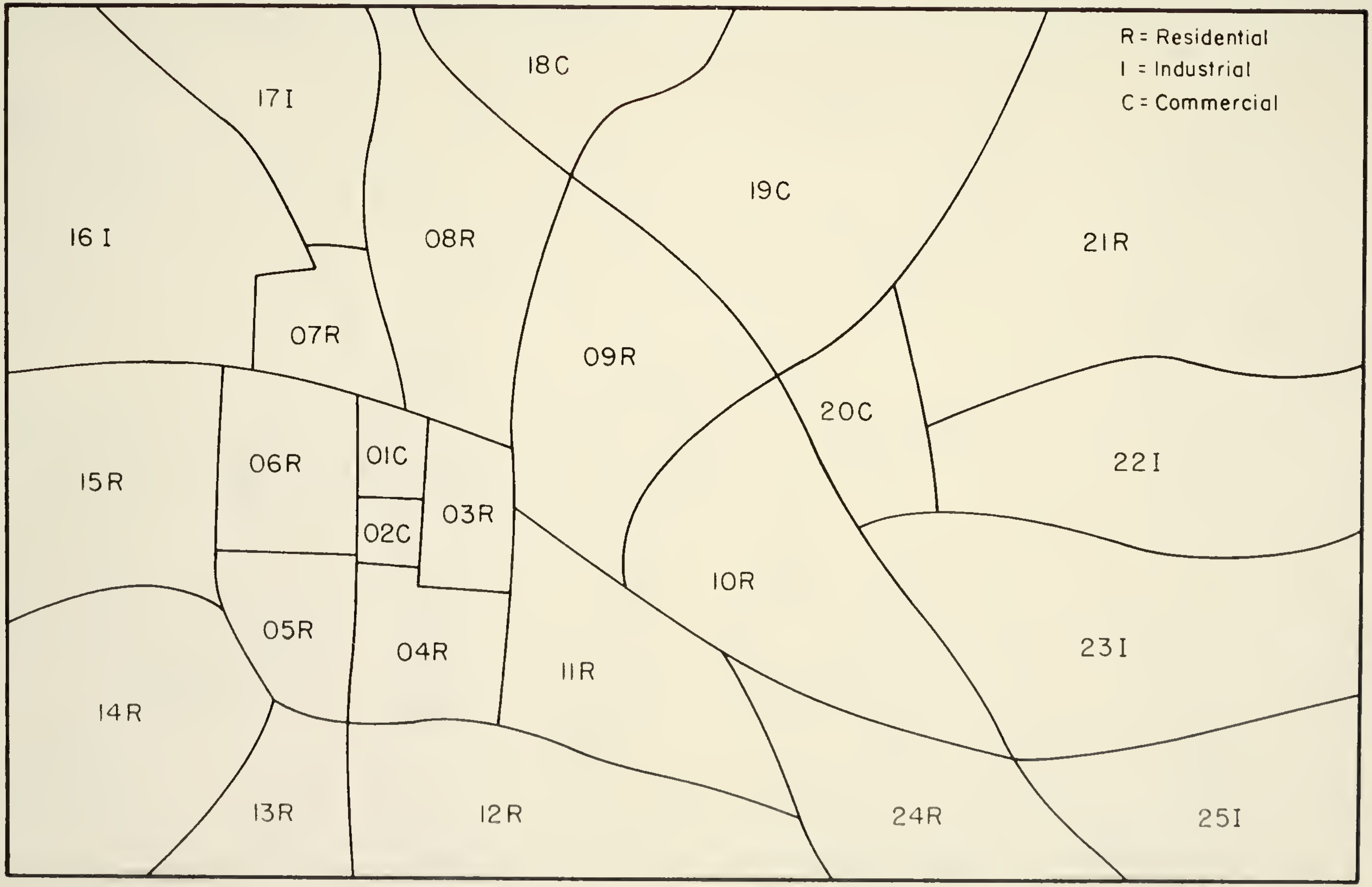

Fig. 27 Origin and Destination Zones

Monroe, N.C.

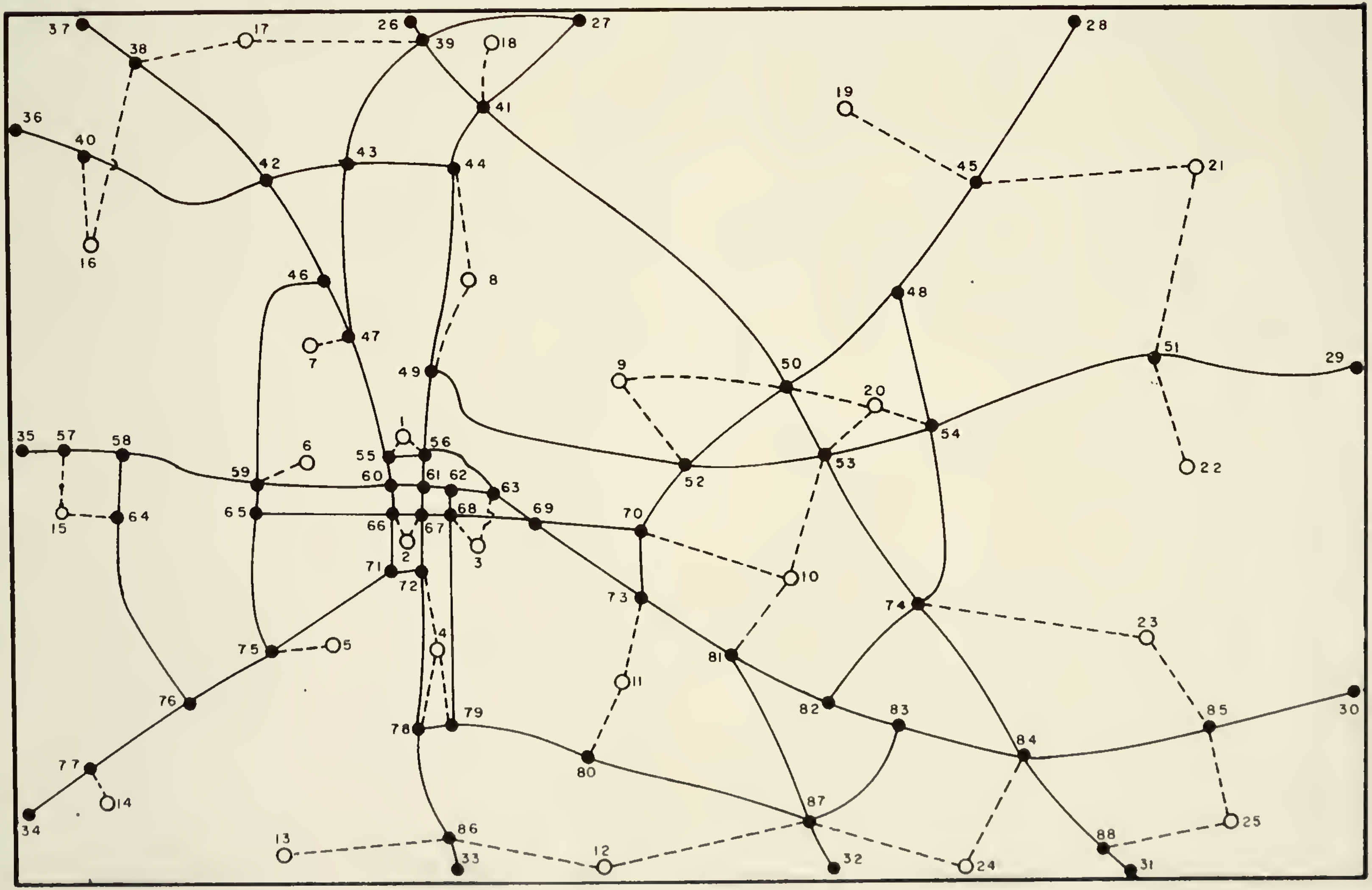

Fig.28 Coded Network
Monroe, N.C

daily trips. Transfers from any zone "i" to any other zone "j" were assumed to be equal to those made from zone "j" to zone "i".

Interzonal Levels of Service

Five service level combinations were selected to evaluate the effects of the choice of interzonal levels of service on the evaluation of an existing or porposed plan. These combinations account for variations in the purpose and location of the urban trips as demonstrated in Table 5. The movements within the study area were classified as intra-core, intra-city, to-core, through and all-other trips. The levels of service for the first combination were 10, 15, 15, 25 and 20 mph, respectively. The second, third, fourth and fifth service-level combinations were generated by successively incrementing all levels of service in the first combination by 5 mph.

The influences of superior service levels on the adequacy of a transportation system are represented graphically in Figures 29 through 33, and a summary of these findings is shown in Table 6. Higher levels of service increase zonal deficiencies, and, as a result, link deficiencies are reduced on the system. Therefore, it is important to evaluate a transportation plan in relation to both link and zonal deficiencies simultaneously.

The adequacy of a transportation system does not change linearly with a linear change in the selected levels of service. Deficiencies on a network are more sensitive to changes in levels of service when these levels express average desirable travel qualities rather than

TABLE 5

Level of Service Combinations Used
in Monroe Plan Evaluation

	Corresponding Zones	Level of Service Combination				
		1	2	3	4	5
Intra Core	1,2,3	10	15	20	25	30
Intra City	4 - 11	15	20	25	30	35
To Core	to 1,2,3	15	20	25	30	35
Through	26 - 37	25	30	35	40	45
All Others		20	25	30	35	40

Fig. 29 Deficiencies for Level of Service Combination I

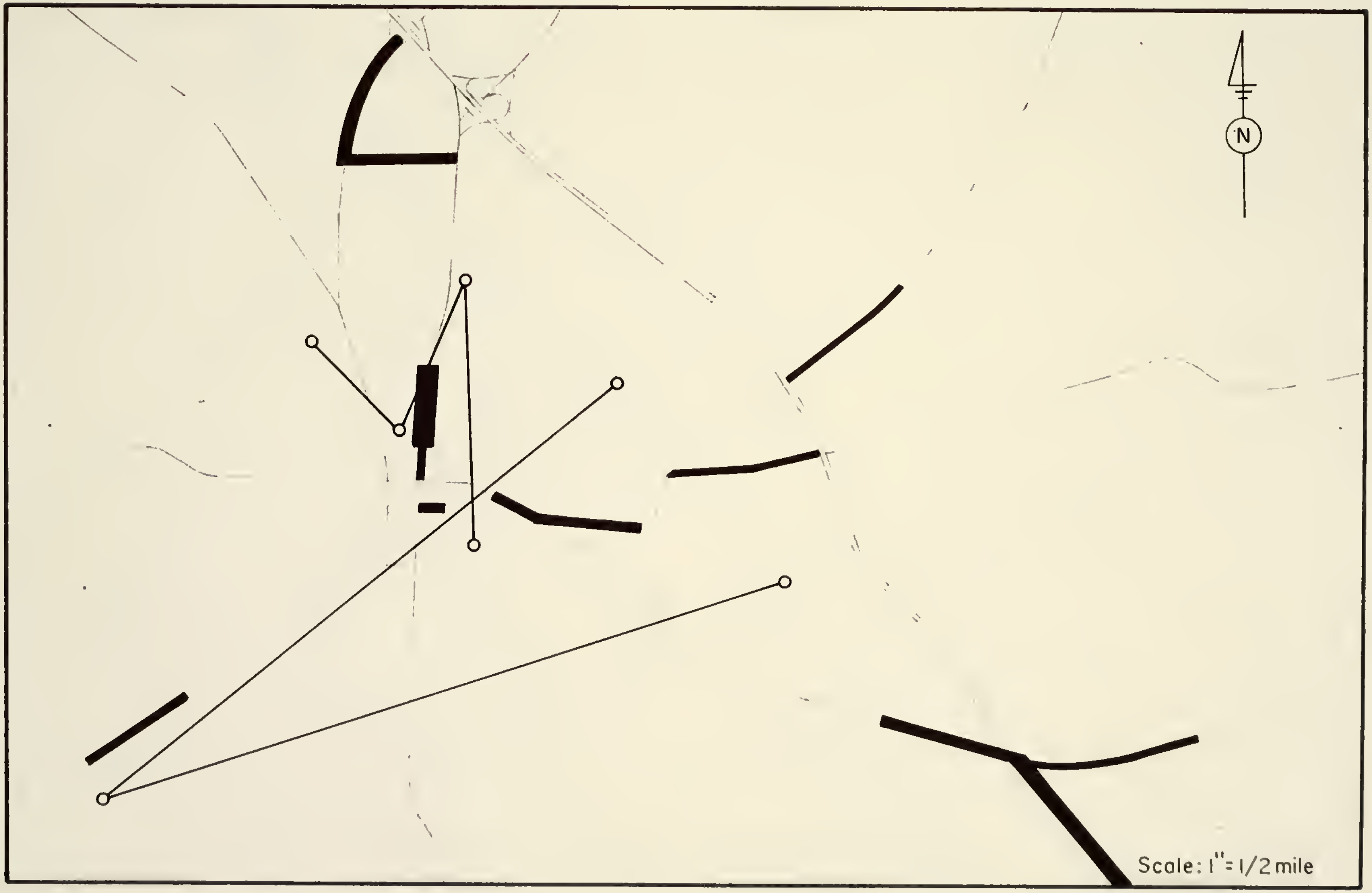

Fig. 30 Deficiencies for Level of Service Combination 2

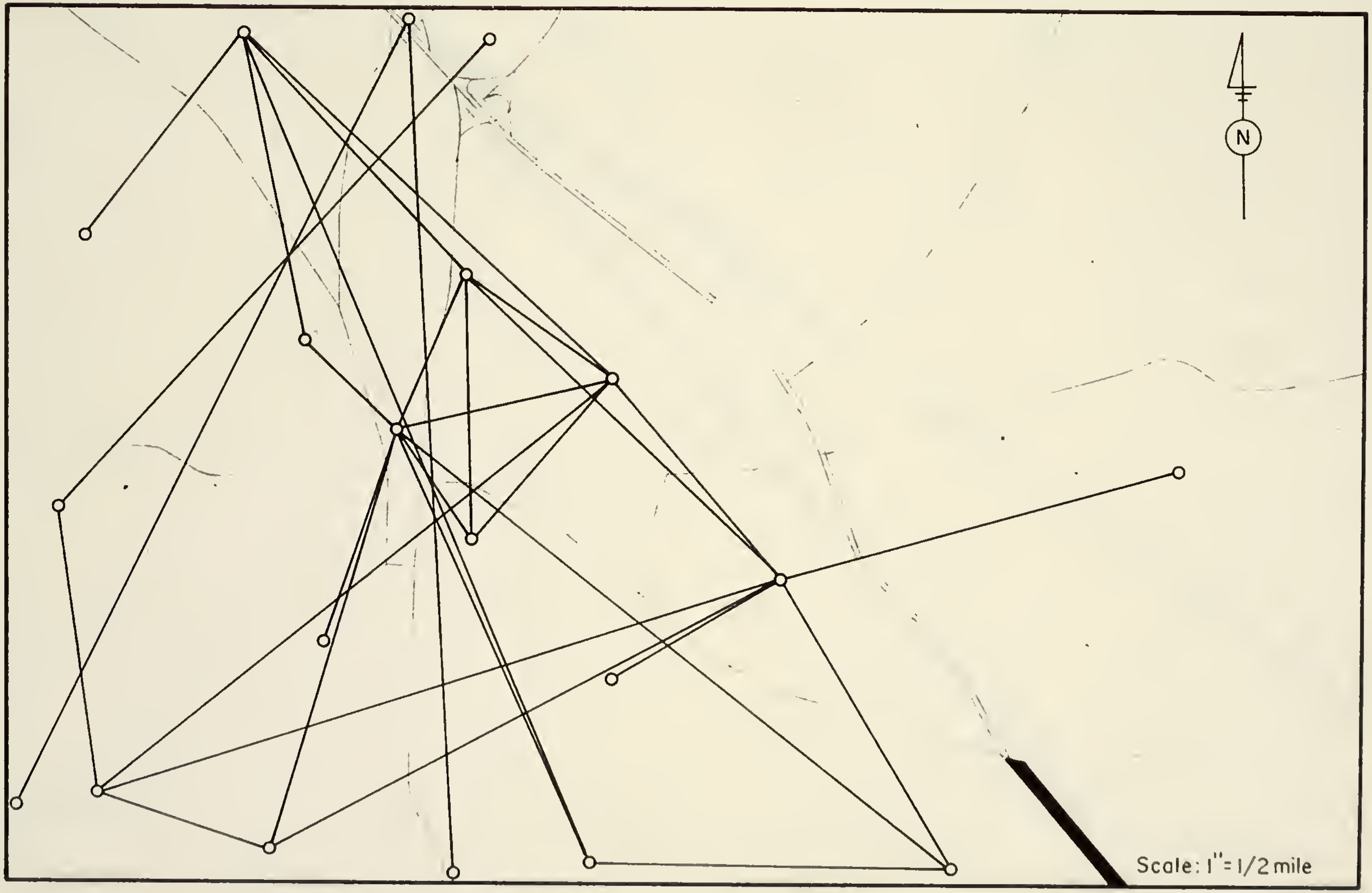

Fig. 31 Deficiencies for Level of Service Combination 3

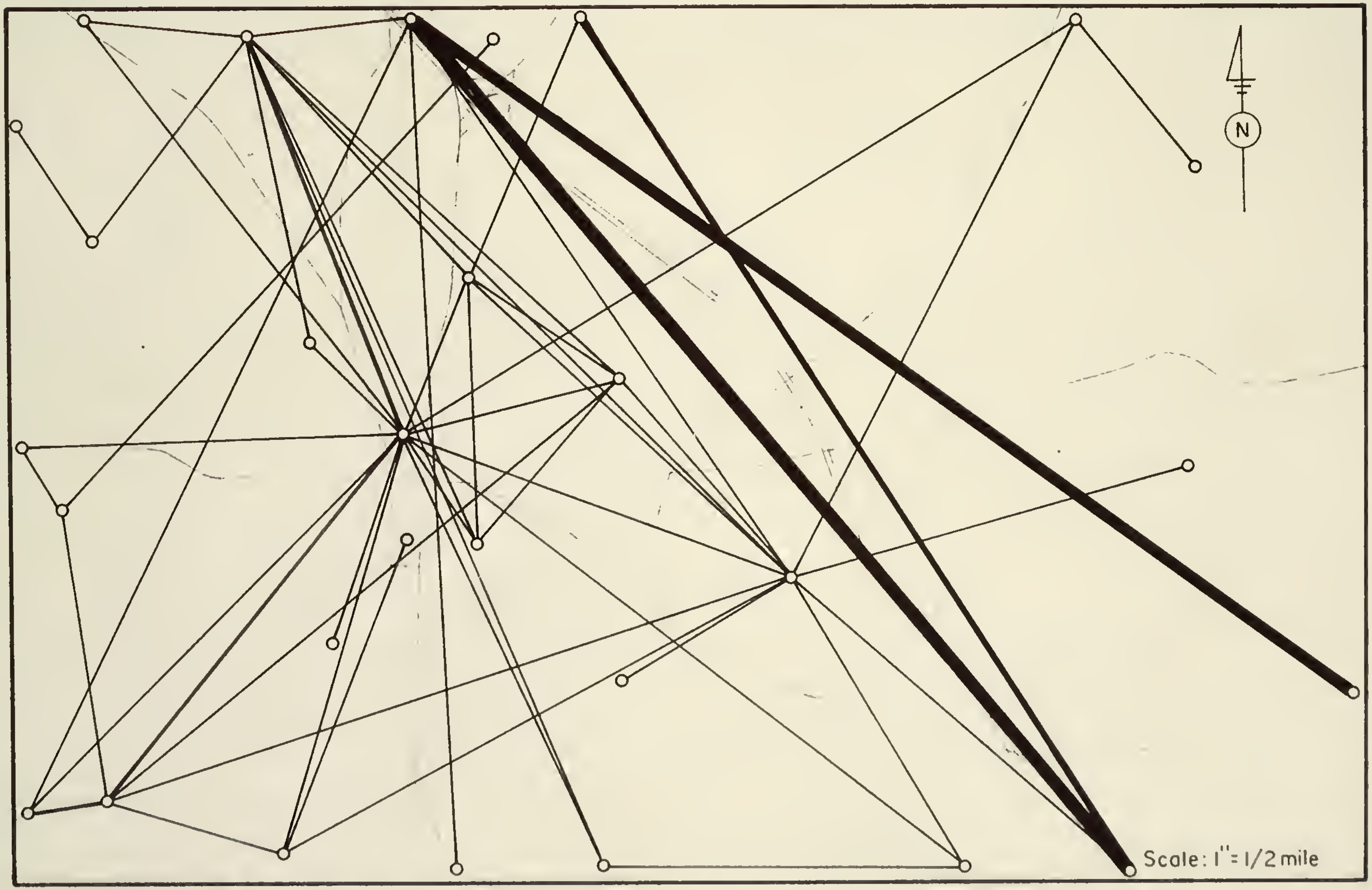

Fig. 32 Deficiencies for Level of Service Combination 4

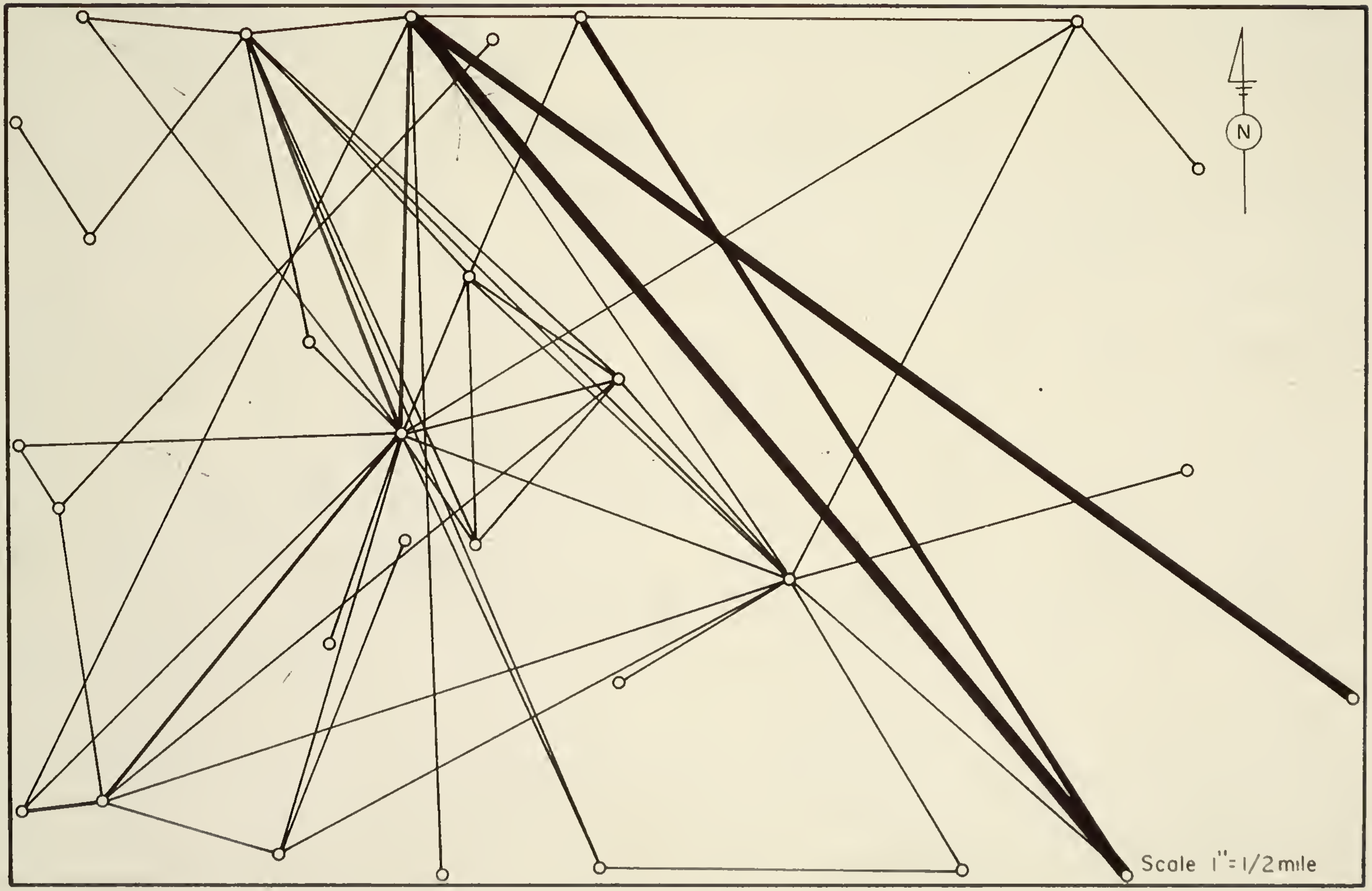

Fig. 33 Deficiencies for Level of Service Combination 5

TABLE 6

Deficiencies for Various Interzonal Level
of Service Combinations

	Level of Service Combination				
	1	2	3	4	5
Percent of Links Deficient	38	30	5	0	0
Percent of Trip Combinations Deficient	0	9	57	96	100
Percent of Trip Interchanges Deficient	0	4	23	46	100
Vehicle-miles of Link Deficiencies	2200	1450	165	0	0
Vehicle-miles of Zonal Deficiencies*	0	1320	8240	20780	21080

*Based on airline distance.

very high or very low overall speeds. This conclusion is demonstrated by the data presented in Table 6. A change from the second to the third level of service combination, both of which describe average speeds in urban areas, increases the zonal deficiencies by 48 percent. On the other hand, the replacement of the fourth by the fifth combination, both of which define superior driving qualities, results in only a 4-percent increase in zonal deficiencies.

A procedure was adopted to detect the cause of zonal deficiencies. These deficiencies may occur because of high impedance values used on selected street links. To guide in the determination of these inadequate links causing zonal deficiencies, the assignment technique is employed for zonal deficiencies only and with levels of service that are lower than the desired values. If the modified levels of service are selected low enough, this procedure results in the allocation of all trip interchanges to the transportation system. The analysis of the impedance values on the links that carry appreciable loads in this assignment aids in the detection of the cause of zonal deficiencies that occur when the acceptable levels of service are specified.

Qualities of Traffic Flow

The adequacy of a proposed plan depends on the desired qualities of traffic flow on the various components of the transportation system. These qualities are described as link levels of service in accordance with the classification suggested in the Highway Capacity Manual (13). Link levels of service B, C, and D were selected in this analysis to evaluate the adequacy of the transportation network for Monroe. The speeds and volume-to-capacity ratios for these service levels are shown in Table 7.

The interzonal levels of service in this portion of the analysis are indicated by the second combination in Table 5. The deficiencies which are obtained from the assignment operations for the three link levels of service are summarized in Table 3 for the transportation system of Monroe. These tabulated values can not be used to explain the adequacy of the system without analyzing the cause for the variations among these tabled figures. Reductions in the link levels of service, accompanied by increased impedance values, preclude the availability of some acceptable routes and result in increased zonal deficiencies. This fact explains the excess zonal deficiencies for level of service "D" over that for level "C". A network with an acceptable service level "D" can accommodate at least as much traffic as with an acceptable service level "C" for this study system. Thus, the true zonal deficiencies on a system using inferior qualities of traffic flow must be determined for several assignment operations. The procedure for obtaining the actual measure of the zonal deficiencies is explained under the section entitled "Selection of the Quality of Traffic Flow".

TABLE 7

Speeds and Volume to Capacity Ratios
for Various Link Levels of Service

Link Level of Service		B	C	D
Speed (mph)	Core	25	20	15
	City	30	25	20
	Fringe	30	30	25
Volume to Capacity Ratio		0.7	0.8	0.9

TABLE 8

Deficiencies for Various Link Levels of Service

	Link Level of Service		
	B	C	D
Percent of Links Deficient	53	30	6
Percent of Trip Combinations Deficient	2	9	24
Percent of Trip Interchanges Deficient	1	4	14
Vehicle-miles of Link Deficiencies	8,300	1,450	500
Vehicle-miles of Zonal Deficiencies *	160	1,320	5,500

* Based on airline distance.

APPLICATION OF THE SIMPLIFIED PROPORTIONAL ASSIGNMENT TECHNIQUE

The application of the Simplified Proportional Assignment Technique is demonstrated in the following sections. The City of Monroe, North Carolina, was selected as the study area in this phase of the investigation. The data concerning the projected traffic movements on the network of this community were obtained from a study report prepared by North Carolina State Highway Commission (28). Because this study report lacked information related to the characteristics of the transportation system, geometric features of the links and operational conditions at intersections were assumed to complete this demonstration. Some modifications on the street layout and the zonal subdivisions were introduced to obtain a clearer and simpler evaluation of the transportation system.

The study objectives as related to transportation were assumed to provide the community with the second level of service combination shown in Table 5. This combination describes acceptable travel speeds ranging from 15 mph for intra-core movements to 30 mph for through trips. The desired quality of traffic flow on the links of the street network was selected to be level of service "C" as specified in the Highway Capacity Manual (13). The impedances and service volumes for the various links were established from the information provided in Table 7.

The proposed assignment procedure was first applied to the existing transportation system for the origin and destination zones shown in Figure 27 and the coded network described in Figure 28. The computer program that was employed in the assignment technique is outlined in Appendix B. Both link and zonal deficiencies existed on the network after the evaluation of the system by the Simplified Proportional Assignment Technique. These deficiencies are described in Tables 9 and 10 under the heading entitled "Existing System". A total of 19 trip interchange combinations had zonal deficiencies, and 4169 unaccommodated vehicles constituted the link deficiencies on the system.

The nature and location of the needed improvements were then determined by analyzing the deficiencies that resulted from the evaluation process. To demonstrate the effects of the adopted improvements on the adequacy of the transportation system, the proposed facilities that would accommodate the excess traffic were considered in three successive stages. These stage improvements are shown in Figure 34.

The first stage of the recommended improvements included the construction of an expressway segment between nodes 72 and 49 and a street section between nodes 47 and 49. The SPAT computer program was employed again with the first proposed transportation plan. This plan featured the inclusion of the first set of improvements on the existing transportation system. The zonal and link deficiencies resulting from the new assignment process are detailed in Tables 9 and 10 under the heading "First Stage Improvements". The first stage of

TABLE 9

Link Deficiencies

Link	Existing System	First Stage Improvements	Second Stage Improvements	Third Stage Improvements
31 - 88	288	290	-	-
39 - 43	314	268	268	280
42 - 43	70	-	-	-
43 - 44	150	-	-	-
46 - 59	32	-	-	-
48 - 50	136	135	-	-
49 - 56	536	358	560	560
50 - 52	65	71	-	-
52 - 53	162	154	164	140
53 - 54	68	69	71	68
54 - 74	82	71	72	71
56 - 61	210	131	132	92
61 - 67	91	-	-	-
6[illegible] - 69	172	80	80	-
66 - 67	130	-	-	-
67 - 68	230	-	-	-
69 - 70	296	186	186	-
69 - 73	57	16	16	-
72 - 78	-	96	100	-
75 - 76	28	50	50	-
76 - 77	222	242	-	-
78 - 86	64	146	150	152
83 - 84	314	338	-	-
84 - 85	192	190	-	-
84 - 88	280	282	-	-
Total	4169	3173	1649	1163

TABLE 10

Zonal Deficiencies

Link	Existing System	First Stage Improvements	Second Stage Improvements	Third Stage Improvements
3 - 7	x			
4 - 10	x	x	x	
4 - 15	x	x	x	
4 - 18	x			
7 - 12	x			
7 - 13	x			
8 - 12	x			
8 - 13	x			
8 - 14	x			
9 - 14	x	x	x	
10 - 14	x	x	x	
11 - 15	x	x	x	
11 - 16	x			
27 - 33	x			
30 - 34	x	x	x	
31 - 34	x	x	x	
31 - 35	x	x	x	x
33 - 35	x	x	x	
33 - 37	x			

x = Existence of a Zonal Deficiency.

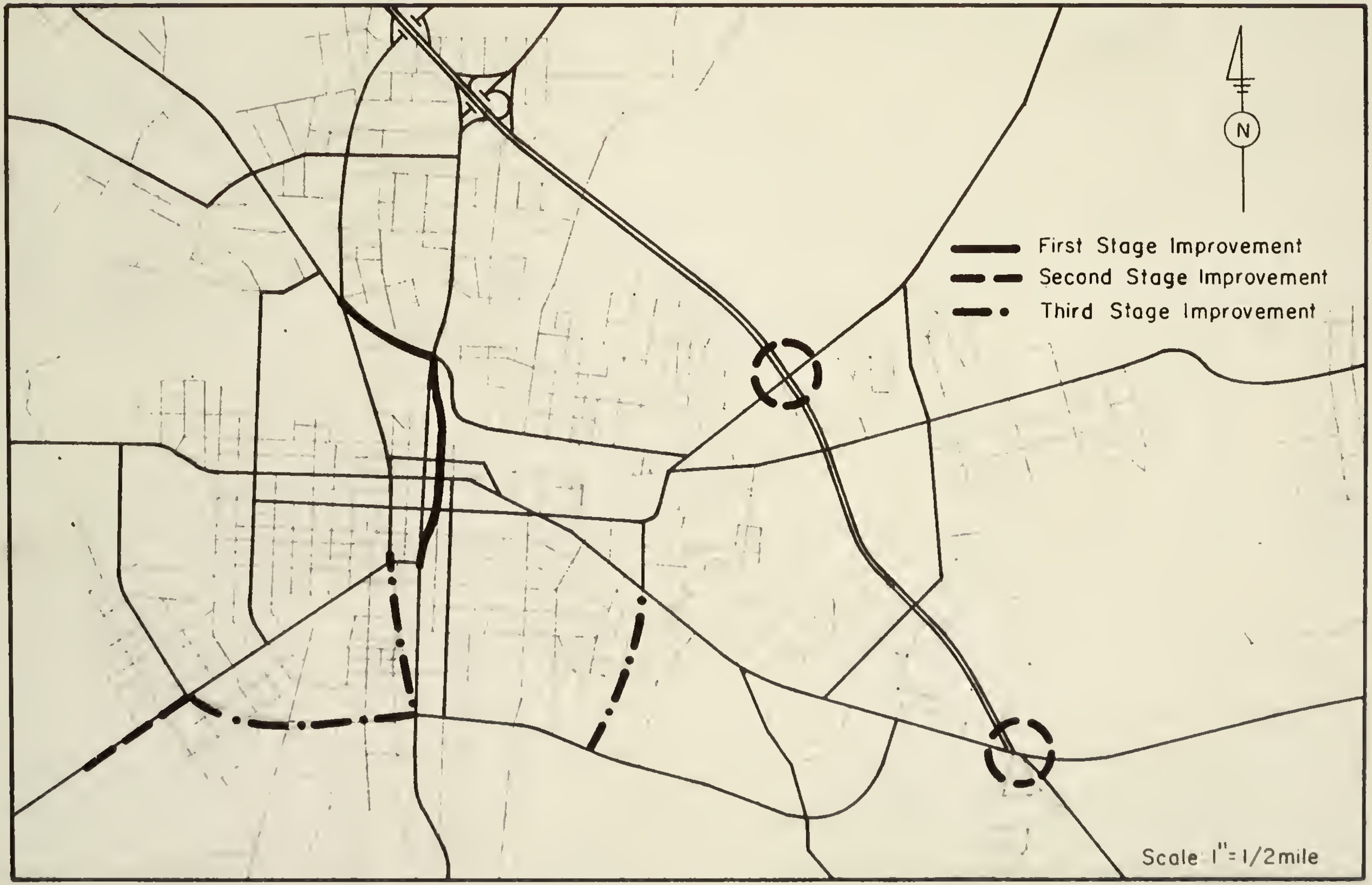

Fig. 34 Stage Improvements

improvements has reduced the zonal deficiencies from 19 to 9 in number and has decreased the link deficiencies from 4169 to 2173 unaccommodated vehicles.

A second set of improvements was then proposed. These modifications included two interchanges at nodes 50 and 84 and a widening of the street segment between nodes 76 and 77 to four lanes. The computer program of SPAT was applied another time to the expanded network comprising the existing and proposed facilities. The resulting deficiencies are shown in Tables 9 and 10 under the heading "Second Stage Improvements". Although the number of zonal deficiencies was not affected by the second set of improvements, the link deficiencies were reduced from 2173 to 1649 unaccommodated vehicles. New facilities were further adopted, and the system evaluation technique was again employed for the newly proposed plan. The third set of improvements included three street segments as shown in Figure 14. These segments provide direct connections between the zonal pairs 76-78, 71-78 and 73-80. The obtained deficiencies from the last assignment are presented in the column entitled "Third Stage Improvements" of Tables 9 and 10. The resulting inadequacies include one zonal deficiency and 1163 unaccommodated vehicles on deficient links. The link deficiencies ranged in value from 68 to 360 vehicles per link.

Although the three stages of improvement did not result in full attainment of the study objectives, some congestion on a few links was considered acceptable. The needed improvements to account for the resulting inadequacies of one zonal deficiency and seven deficient links did not appear to justify further investment to eliminate these deficiencies. In transportation studies performed by operating agencies, minor localized deficiencies may be tolerated at lower levels of service when these deficiencies require unjustifiable investments to accommodate the excess traffic on the system.

The Monroe street network, which was used in demonstrating the application of the Simplified Proportional Assignment Technique had 37 zonal centroids, 88 nodes and 264 links. The average computer time to execute a complete assignment operation for this network was 6 minutes.

SUMMARY AND CONCLUSIONS

This research investigation was concerned with the development of a new concept in traffic assignment for the evaluation of urban transportation systems. The formulated concept was designated as the Simplified Proportional Assignment Technique, or SPAT. The following operations comprise the main features of the technique.

1. The study objectives as related to transportation in a community are expressed as the attainment of specific levels of service between pairs of urban zones within the study area.

2. All routes that can move traffic at these prescribed levels of service are determined, and trip interchanges are assigned to these routes on a proportional basis. The evaluation procedure may result in the detection of zonal and/or link deficiencies. A zonal deficiency represents the absence of a route that can move traffic at the established service level, and a link deficiency occurs when the desirability to use a street segment exceeds the ability of this segment to provide a specified quality of traffic flow.

3. This procedure is applicable to either an existing or a proposed transportation system. The adequacy of a proposed plan is confirmed when the transportation facilities are able to accommodate a given set of trip interchanges at the desired levels of operation without the presence of either zonal or link deficiencies.

The acceptable routes in SPAT are obtained by specifying an upper limit on the percentage of route overlap between two or more corridors of travel. A 7-percent overlap at either end of the routings provided the best corridor representation of the acceptable routes in the analysis of the selected trip interchanges in Indianapolis, Indiana. A further limitation was placed on the number of acceptable paths for more efficient use of the proposed technique. The travel time and total distance for all acceptable routes was not permitted to exceed 1.75 of the corresponding values on the minimum-time path.

The Simplified Proportional Assignment Technique is a practical and reliable procedure for system evaluation. The use of the technique in urban transportation studies permits the quantitative determination of the adequacies of proposed plans. Because the use of SPAT to evaluate a transportation plan is achieved by direct reference to the study objectives, differences among communities in desires and resource limitations are incorporated in the procedure. The Simplified Proportional Assignment Technique provides a rational technique that employs traffic assignment to quantify the adequacies and deficiencies of urban transportation systems.

RECOMMENDATIONS FOR FURTHER RESEARCH

The Simplified Proportional Assignment Technique, which was formulated in this research investigation, covers several areas related to traffic engineering and transportation planning. Although this technique has been developed to an operational stage in this study, further research is needed to refine some phases of the assignment process. The needed work pertains primarily to community objectives, driver characteristics and computer programming. The following recommendations are presented to define specific research activities designed to refine the application of SPAT in system evaluation.

1. The selected interzonal levels of service and qualities of traffic flow on a transportation system determine to a large degree the costs associated with an adopted plan that meets the study objectives. Research is warranted to determine the sensitivity of variations in these decision-making parameters on the development of transportation plans. Such work would guide in the selection of the proper values for these parameters and would establish the extent to which improved travel conditions for the road user justify additional expenditures.

2. The allocation of trip interchanges to alternate routes in the Simplified Proportional Assignment Technique is performed on a proportional basis that accounts for differences in travel time, route distance and tension experienced in driving the route. Further

research is required to evaluate the relative importance of these factors, and, in particular, the exponent of each variable used in the proportioning of traffic to the alternate acceptable routes. The evaluation of these factors should account for differences in trip purpose and length.

[illegible]. The computer program developed in this research investigation is limited to the evaluation of transportation systems for medium-size communities. Because this program was developed to demonstrate the validity of the SPAT concept, additional efforts in improving the efficiency of the computer program are suggested to permit the evaluation of large urban transportation systems by the Simplified Proportional Assignment Technique.

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APPENDIX A

List of the Computer Program Definitions

APPENDIX A

List of the Computer Program Definitions

ACTSL	:	The level of service actually provided by a particular route.
AM(I)	:	The number of nodes on route I expressed as a real number.
DCUM(I)	:	The cumulative distance from the origin to the end of link I.
DLINK(I)	:	The length of link I.
DMIN	:	The distance value corresponding to TMIN.
DOTAL(I)	:	The total distance on route I.
DSUM(I)	:	The cumulative distance from an origin to the end of link I corresponding to the path of TSUM(I).
F(I)	:	The attractiveness factor of route I.
FD(I)	:	The distance factor of route I.
FN(I)	:	The node factor of route I.
FT(I)	:	The travel time factor of route I.
FTOTAL	:	The summation of the attractiveness factors of all the acceptable routes between an origin-destination pair.
ICAP(I)	:	The service volume on link I.
IDEF(I)	:	The deficiency on link I.
ILAST	:	The acceptable route with the highest travel time.
INDEX	:	An index to identify the order of an acceptable route.

IZONE	:	An index to identify the order of the origin zone.
J(I)	:	The "to" node of link I.
JJ	:	The maximum fraction of a minimum path, at either end, that can be shared by two or more alternate routes.
JJ1	:	The first node on a path segment that can be shared by more than one route.
JJ2	:	The last node on a path segment that can not be shared by more than one route.
JP	:	The "from" node identifying a particular link.
KK(I,J)	:	The index of the I-th node from an origin on the J-th route.
LASTCD	:	A variable used to identify the last card of the trip interchange descriptions.
LOADD(I)	:	The total assigned trips to link I.
LOAD(I,J)	:	The trips assigned to the I-th link from consideration of the J-th route.
LLOADD(I)	:	A variable used to store one-directional assignments on link I for later addition to assignments made in the other direction.
LTRIP(I)	:	The number of trips assigned to route I converted to integer form.
M(I)	:	The number of nodes on route I.
MEND	:	The number of trip interchange combinations with no acceptable routes.
MINDEX	:	The number of links on the route being considered.
MS	:	An index to identify the order of the links that comprise a route.
MTRIPS(I)	:	The zonal deficiency for trip interchange I.
N(I)	:	The "from" node of link I.
NR	:	An index to identify the order of the origin zone with no acceptable route to its destination.

NCM	:	An index for entry in the cumulative table of the R.R.L. algorithm.
NCUM(I)	:	The link number for entry in the cumulative table of the R.R.L. algorithm.
NDEST	:	The destination node of a route.
NEND	:	The number of trip interchange combinations with no acceptable routes.
NFROM(I)	:	The origin node of the I-th trip interchange combination having no acceptable route.
NHOME	:	The origin node of a route.
NLINK	:	The number of one-way links in the network.
NM	:	An index to speed up link table search for the minimum path.
NN(I)	:	The link number of the nearest node on a minimum path used in the tree table of the R.R.L. algorithm.
NP	:	The "to" node identifying a particular link.
NTO(I)	:	The destination node of the I-th trip interchange combination having no acceptable route.
NZONE	:	The number of nodes in the network.
PERLAP	:	The maximum permissible percent overlap between two alternate routes at either end of these routes.
SAVE(I)	:	A variable used to store the TLINK description of link I.
TCUM(I)	:	The cumulative time from the origin to the end of link I.
TLINK(I)	:	The travel time over link I.
TMIN	:	A variable used in searches for minimum entry in tables.
TOTAL(I)	:	Total travel time on route I.
TRIP(I)	:	The number of trips assigned to route I.

TRIPS	:	The number of trip interchanges between the origin-destination pair under consideration.
TSUM(I)	:	The minimum time from the origin to the end of link I used in the tree table of the R.R.L. algorithm.
VLINK(I)	:	The speed on link I.
VSL	:	The acceptable level of service expressed as a minimum overall speed between an origin and a destination.

APPENDIX B

Computer Program for the Simplified Proportional Assignment Technique

APPENDIX B

Computer Program for the Simplified Proportional Assignment Technique

```
      DIMENSION N(500),J(500),TLINK(500),TCUM(800)
      DIMENSION DSUM(300),DCUM(800),NCUM(800)
      DIMENSION NN(300), TSUM(300),SAVE(300),DLINK(500)
      DIMENSION FT(100),FD(100),FL(100),F(100),TRIP(100)
      DIMENSION LTRIP(100),LOAD(300,10),KK(300,10)
      DIMENSION M(10),AM(10),MM(10),VLINK(500)
      DIMENSION TOTAL(100),DOTAL(100)
      DIMENSION LOADD(500),LLOADD(500)
      DIMENSION ICAP(500),IDEF(500)
      DIMENSION NFROM(1000),NTO(1000),NTRIPS(1000)
101   FORMAT (2I10,2F10.0,I10)
102   FORMAT (2I10,2F10.2)
300   FORMAT (2I10,F10.1)
C     READ THE NETWORK DESCRIPTION AND TRIP TABLE
      READ (5,300)NZONE,NLINK,PERLAP
      N(NLINK+1)=0
      IZONE=0
      DO 1 I=1,NLINK
      LOADD(I)=0
      NB=0
      READ(5,101)N(I),J(I),DLINK(I),VLINK(I),ICAP(I)
1     TLINK(I)=DLINK(I)*75.0/VLINK(I)/152.0
52    READ(5,101) NHOME,NDEST,TRIPS,VSL,LASTCD
      IF (LASTCD.EQ.1)GO TO 450
      WRITE (6,700)
700   FORMAT (29H0   FROM     TO     VSL     PERLAP )
      WRITE (6,81) NHOME,NDEST,VSL,PERLAP
81    FORMAT (2I7,2F7.1)
      IZONE=IZONE+1
      DO 75 I=1,NLINK
75    SAVE(I)=0.0
      INDEX=0
62    DO 111 I=1,NZONE
2     TSUM(I)=99999.99
111   DSUM(I)=0.0
      INDEX=INDEX+1
      NN(NHOME)=0
      TSUM(NHOME)=0
```

```
      NCM= 0
      NM=NHOME
C     PROHIBIT THE USE OF CENTROIDS AS INTERMEDIATE NODES ON A ROUTE
6     IF (NM.GT.27) GO TO 501
      IF (NM.EQ.NHOME) GO TO 501
      GO TO 8
C     SEARCH FOR THE BEST ROUTE
501   DO 7 I=NM,NLINK
      IF (N(I)-NM) 7,3,8
3     K=J(I)
      IF (TSUM(K)-99999.99) 7,18,7
18    NCM=NCM+1
      TCUM(NCM)=TSUM(NM)+TLINK(I)
      DCUM(NCM)=DSUM(NM)+DLINK(I)
      NCUM(NCM)=I
7     CONTINUE
8     TMIN=99999.99
      DO 9 K=1,NCM
      IF (TMIN-TCUM(K)) 9,9,10
10    TMIN=TCUM(K)
      DMIN=DCUM(K)
      L=NCUM(K)
      MP=K
9     CONTINUE
      K=J(L)
      IF (TSUM(K)-TMIN) 11,11,13
11    I=1
      GO TO 12
13    TSUM(K)=TMIN
      DSUM(K)=DMIN
      NN(K)=L
      I=0
      IF (NDEST-K) 12,70,12
12    DO 14 NM=MP,NCM
      TCUM(NM)=TCUM(NM+1)
      NCUM(NM)=NCUM(NM+1)
      DCUM(NM)=DCUM(NM+1)
      IF (NM+1-NCM) 14,15,14
14    CONTINUE
15    NCM=NCM-1
      IF (I) 8,17,8
17    NM=K
      GO TO 6
C     CALCULATE THE ACTUAL SERVICE LEVEL AND
C     COMPARE IT WITH THE ACCEPTABLE ONE
70    ACTSL=DSUM(K)*75.0/TSUM(K)/132.0
      WRITE (6,120) ACTSL
120   FORMAT(30X,18HAVERAGE SPEED IS  ,F6.2)
      IF (ACTSL.LT.VSL) GO TO 73
```

```
      MS=1
      KK(MS,INDEX)=K
      I=KK(MS,INDEX)
      TOTAL(III)=TSUM(I)
      DOTAL(III)=DSUM(I)
      GO TO 699
51    KK(MS,INDEX)=K
      I=KK(MS,INDEX)
C     WRITE THE DESCRIPTION OF THE ACCEPTABLE ROUTE
400   WRITE (6,102) MS,I,TSUM(I),DSUM(I)
      IF (I-NHOME) 64,71,64
C     REMOVE THE CENTRAL PART OF THE ACCEPTABLE ROUTE
71    AM(INDEX)=MS
      M(INDEX)=MS
      TOTAL(INDEX)=TOTAL(III)
      DOTAL(INDEX)=DOTAL(III)
      JJ=MS/10
      JJ1=JJ+3
      JJ2=MS-JJ-2
      IF (MS.EQ. ) JJ1=2
      IF (MS.EQ. ) JJ2=3
      IF (MS.EQ.4) JJ1=2
      IF (MS.EQ.4) JJ2=4
      DO 72 I=JJ1,JJ2
      K=KK(I,INDEX)
      L=NN(K)
      SAVE(L)= TLINK(L)
72    TLINK(L)=1000.0
      GO TO 62
64    L=NN(I)
      K=N(L)
      MS=MS+1
      GO TO 51
73    ILAST=INDEX-1
      IF (ILAST.EQ.0) GO TO 403
      WRITE (6,83)
83    FORMAT (45X,25HNO MORE ACCEPTABLE ROUTES)
C     CALCULATE THE ATTRACTIVENESS FACTORS OF THE ACCEPTABLE ROUTES
C     AND THE TRIPS TO BE ASSIGNED TO EACH
      FTOTAL=0.0
      DO 401 INDEX=1,ILAST
      FT(INDEX)=1.0/TOTAL(INDEX)
      FD(INDEX)=1.0/DOTAL(INDEX)
      FN(INDEX)=1.0/(AM(INDEX)-2.0)
      F(INDEX)=FT(INDEX)*FD(INDEX)*FN(INDEX)
401   FTOTAL=FTOTAL+F(INDEX)
      DO 402 INDEX=1,ILAST
      TRIP(INDEX)=F(INDEX)/FTOTAL*TRIPS
      LTRIP(INDEX)=TRIP(INDEX)
      IF (INDEX.EQ.2) LTRIP(INDEX)=LTRIP(INDEX)+1
```

```
      IF (INDEX.EQ.4) LTRIP(INDEX)=LTRIP(INDEX)+1
402   WRITE (6,603) INDEX,LTRIP(INDEX)
603   FORMAT (13H ROUTE NUMBER,I4,5X,14HASSIGNED TRIPS,I7)
      GO TO 405
403   WRITE(6,404)
404   FORMAT (45X, 26HNO ACCEPTABLE ROUTE EXISTS)
      NB=NB+1
      NFROM(NB)=NHOME
      NTO(NB)=NDEST
      MTRIPS(NB)=TRIPS
      WRITE(6,701)MTRIPS(NB)
701   FORMAT (45X,19HZONAL DEFICIENCY IS,I7)
      GO TO 52
405   DO 419 L=1,NLINK
      DO 419 INDEX=1,ILAST
419   LOAD(L,INDEX)=0
      DO 440 INDEX=1,ILAST
      MINDEX=M(INDEX)-1
      DO 440 I=1,MINDEX
      JP=KK(I,INDEX)
      NP=KK(I+1,INDEX)
      DO 960 I1=1,NLINK
      IF (N(I1).EQ.NP.AND.J(I1).EQ.JP) LX=I1
960   CONTINUE
C     ASSIGN THE TRIPS TO THE LINKS
      LOAD(LX,INDEX)=LTRIP(INDEX)
440   CONTINUE
421   FORMAT (4I10)
      DO 490 L=1,NLINK
      DO 422 INDEX=1,ILAST
422   LOADD(L)=LOADD(L)+LOAD(L,INDEX)
490   CONTINUE
423   FORMAT(3I7)
C     RE-ESTABLISH THE FULL NETWORK DESCRIPTION
424   DO 76 L=1,NLINK
      IF (SAVE(L).EQ.0.0) GO TO 76
74    TLINK(L)=SAVE(L)
76    CONTINUE
      GO TO 52
430   NEND=NB
      WRITE (6,800)
800   FORMAT(1H1,13X,17HLINK DEFICIENCIES,43X,18HZONAL DEFICIENCIES)
      WRITE (6,702)
702   FORMAT(1HO,5X,4HFROM,4X,2HTO,4X,4HLOAD,5X,8HCAPACITY,1X,
     15HDEFCY,30X,4HFROM,4X,2HTO,2X,11HZONAL DEFCY)
      DO 801 LL=1,NEND
      IDEF(LL)=LOADD(LL)-ICAP(LL)
      IF (IDEF(LL).LE.0) IDEF(LL)=0
801   WRITE (6,802) N(LL),J(LL),LOADD(LL),ICAP(LL),IDEF(LL),
     1NFROM(LL),NTO(LL),MTRIPS(LL)
```

```
802   FORMAT (5I8,26X,I8,I7,I9)
      MEND=NEND+1
      DO 431 LX=MEND,NLINK
      IDEF(LX)=LOADD(LX)-ICAP(LX)
      IF (IDEF(LX).LE.0) IDEF(LX)=0
431   WRITE (6,432) N(LX),J(LX),LOADD(LX),ICAP(LX),IDEF(LX)
432   FORMAT (5I8)
C     SUMMARIZE THE DESCRIPTION OF THE LOADED NETWORK
      WRITE (6,507)
507   FORMAT (1H1,17X,7HSUMMARY)
      WRITE (6,508)
508   FORMAT(1HO,5X,4HFROM,4X,2HTO,4X,4HLOAD,3X,8HCAPACITY,1X,5HDEFCY)
      DO 505 J4=1,NLINK
      IF (N(J4).GT.J(J4)) GO TO 505
      DO 504 J5=1,NLINK
      IF (N(J4).EQ.J(J5)) GO TO 502
      GO TO 504
502   IF (J(J4).EQ.N(J5)) GO TO 503
      GO TO 504
503   LLOADD(J4)=LOADD(J4)
      LOADD(J4)=LOADD(J4)+LOADD(J5)
      LOADD(J5)=LOADD(J5)+LLOADD(J4)
      IDEF(J4)=LOADD(J4)-ICAP(J4)
      IF (IDEF(J4).LE.0) IDEF(J4)=0
      IDEF(J5)=LOADD(J5)-ICAP(J5)
      IF (IDEF(J5).LE.0) IDEF(J5)=0
      ICAP(J4)=ICAP(J4)+ICAP(J5)
      LOADD(J4)=LOADD(J4)+LOADD(J5)
      IDEF(J4)=IDEF(J4)+IDEF(J5)
504   CONTINUE
      WRITE (6,432) N(J4),J(J4),LOADD(J4),ICAP(J4),IDEF(J4)
505   CONTINUE
      STOP
      END
$DATA
```

APPENDIX C

Travel Characteristics of the Routes

APPENDIX C

Travel Characteristics of the Routes

TABLE C1

Travel Characteristics of the Routes of Zonal Combination 1

Percent Overlap	Route Number	1	2	3	4	5	6	7	8	9	10	11	12
0	T	4.7	6.8	7.2	13.8	15.5							
	D	1.4	1.7	2.4	5.0	6.1							
	V	18.0	15.1	19.9	21.6	23.6							
3	T	4.7	6.8	7.2	13.8	15.5							
	D	1.4	1.7	2.4	5.0	6.1							
	V	18.0	15.1	19.9	21.6	23.6							
5	T	4.7	6.8	7.2	9.7	13.8	17.1	21.6					
	D	1.4	1.7	2.4	3.1	5.0	6.3	8.0					
	V	18.0	15.1	19.9	19.0	21.6	23.8	22.1					
7	T	4.7	6.5	7.1	9.7	13.8	17.1	21.6					
	D	1.4	1.6	2.3	3.1	5.0	6.8	8.0					
	V	18.0	15.0	19.8	19.0	21.6	23.8	22.1					
10	T	4.7	6.5	7.1	7.2	9.3	11.3	15.5	20.9	24.4	26.6	33.4	
	D	1.4	1.6	2.3	2.2	3.0	4.5	5.4	7.5	9.7	10.7	13.1	
	V	18.0	15.0	19.8	18.0	19.0	23.2	20.8	21.3	23.7	24.1	23.5	
15	T	4.7	6.5	7.1	7.2	9.0	9.2	11.6	15.3	21.1	22.0	24.2	28.6
	D	1.4	1.6	2.3	2.2	2.4	2.8	4.5	4.9	7.7	8.2	9.8	11.5
	V	18.0	15.0	19.8	18.0	16.1	18.5	23.2	19.3	21.3	22.3	24.3	24.1
20	T	4.7	6.5	7.1	7.2	8.9	9.0	9.7	9.8	15.1	21.1	21.5	22.9
	D	1.4	1.6	2.3	2.2	2.9	2.4	2.8	3.7	4.8	8.4	3.2	9.1
	V	18.0	15.0	19.8	18.0	19.4	16.1	17.6	22.8	18.9	23.9	22.8	23.7

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C2

Travel Characteristics of the Routes of Zonal Combination 2

Percent Overlap	Route Number	1	2	3	4	5	6	7	8	9	10	11	12
0	T	7.8	8.8	9.9	21.9								
	D	2.9	3.6	3.5	8.7								
	V	22.2	24.4	21.3	23.8								
3	T	7.8	8.8	9.9	21.9								
	D	2.9	3.6	3.5	8.7								
	V	22.2	24.4	21.3	23.8								
5	T	7.8	8.8	9.9	21.9	32.3							
	D	2.9	3.6	3.5	8.7	13.3							
	V	22.2	24.4	21.3	23.8	24.7							
7	T	7.8	8.8	9.9	21.9	32.3							
	D	2.9	3.6	3.5	8.7	13.3							
	V	22.2	24.4	21.3	23.8	24.7							
10	T	7.8	8.8	9.9	21.9	29.3	36.7						
	D	2.9	3.6	3.5	8.7	12.0	15.1						
	V	22.2	24.4	21.3	23.8	24.6	24.7						
15	T	7.8	8.4	9.9	20.1	28.2	36.7	49.8					
	D	2.9	3.5	3.5	7.9	11.3	15.1	21.9					
	V	22.2	24.8	21.3	23.4	24.0	24.7	26.4					
20	T	7.8	8.4	9.9	20.1	28.2	36.5	47.7	52.2				
	D	2.9	3.5	3.5	7.9	11.3	15.0	20.0	22.1				
	V	22.2	24.8	21.3	23.4	24.0	24.7	25.2	25.3				

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C3

Travel Characteristics of the Routes of Zonal Combination 3

Route Number / Percent Overlap		1	2	3	4	5	6	7	8	9	10	11	12
	T	11.8	20.5	25.4									
0	D	5.4	10.4	10.5									
	V	27.2	30.5	24.8									
	T	11.8	20.5	25.4									
3	D	5.4	10.4	10.5									
	V	27.2	30.5	24.8									
	T	11.8	20.5	25.4	40.0								
5	D	5.4	10.4	10.5	16.5								
	V	27.2	30.5	24.8	24.7								
	T	11.8	20.5	20.8	34.4								
7	D	5.4	10.4	8.3	13.5								
	V	27.2	30.5	24.1	23.5								
	T	11.8	19.1	20.8	34.4								
10	D	5.4	9.9	8.3	13.5								
	V	27.2	31.2	24.1	23.5								
	T	11.8	19.1	20.8	34.4	37.1							
15	D	5.4	9.9	8.3	13.5	14.6							
	V	27.2	31.2	24.1	23.5	23.6							
	T	11.8	12.9	16.6	20.5	23.8	34.4	36.7	38.6	41.7			
20	D	5.4	5.3	6.8	10.4	9.6	13.5	14.4	15.0	16.3			
	V	27.2	24.8	24.5	30.5	24.2	23.5	23.6	23.3	23.4			

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C4

Travel Characteristics of the Routes of Zonal Combination 4

Percent Overlap	Route Number	1	2	3	4	5	6	7	8	9	10	11	12
0	T	13.2	16.9	17.4									
	D	5.7	7.5	8.0									
	V	25.8	26.5	27.7									
3	T	13.2	16.9	17.4									
	D	5.7	7.5	8.0									
	V	25.8	26.5	27.7									
5	T	13.2	14.9	17.2									
	D	5.7	7.0	7.9									
	V	25.8	28.2	27.7									
7	T	13.2	14.9	17.2									
	D	5.7	7.0	7.9									
	V	25.8	28.2	27.7									
10	T	13.2	14.9	17.2	18.7	21.0							
	D	5.7	7.0	7.9	7.9	9.1							
	V	25.8	28.2	27.7	25.4	26.1							
15	T	13.2	13.9	17.2	18.7	20.8	21.3	[illegible]	25.3	30.0	30.1	30.6	34.6
	D	5.7	6.4	7.9	7.9	8.9	9.2	10.7	15.1	17.6	14.7	15.3	19.2
	V	25.8	27.8	27.7	25.4	25.7	25.9	27.2	35.8	35.2	29.4	30.0	33.2
20	T	13.2	13.9	17.2	18.0	20.3	20.5	23.5	23.9	25.7	29.6	30.0	32.3
	D	5.7	6.4	7.9	7.8	8.7	9.2	10.6	14.5	13.0	15.1	17.6	16.4
	V	25.8	27.8	27.7	25.8	25.6	26.9	27.0	36.5	30.3	30.6	35.2	30.4

T = travol time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C5

Travel Characteristics of the Routes of Zonal Combination 5

Route Number / Percent Overlap		1	2	3	4	5	6	7	8	9	10	11	12.
	T	16.6	19.1	21.8	26.7								
0	D	6.5	7.5	9.0	13.9								
	V	23.4	23.5	24.8	31.3								
	T	16.6	19.1	21.8	26.7								
3	D	6.5	7.5	9.0	13.9								
	V	23.4	23.5	24.8	31.3								
	T	16.6	19.1	21.1	23.6	27.9	29.8	36.2	41.4	55.1			
5	D	6.5	7.5	8.9	12.8	11.2	11.4	15.6	17.1	23.0			
	V	23.4	23.5	25.3	32.6	24.1	23.0	25.8	24.8	25.0			
	T	16.6	19.1	21.1	23.6	27.9	28.6	33.2	39.1	41.0	52.7	80.4	
7	D	6.5	7.5	8.9	12.8	11.2	11.7	13.3	15.0	16.5	21.9	35.9	
	V	23.4	23.5	25.3	32.6	24.1	24.5	24.1	23.1	23.8	25.0	26.8	
	T	16.6	19.1	20.9	23.2	25.8	28.6	32.6	36.0	40.4	48.3	57.1	
10	D	6.5	7.5	8.8	12.1	10.8	11.7	12.8	14.4	16.[illegible]	18.7	24.7	
	V	23.4	23.5	25.3	31.3	25.2	24.5	23.5	23.9	24.2	23.2	25.9	
	T	16.6	19.1	20.9	23.2	24.6	28.1	30.3	34.2	37.3	41.6	53.6	
15	D	6.5	7.5	8.8	12.1	9.8	11.5	12.5	13.9	15.6	16.2	22.8	
	V	23.4	23.5	25.3	31.3	2[illegible].8	24.6	24.6	24.4	25.1	23.4	25.5	
	T	16.6	19.1	20.9	23.2	23.9	25.9	28.2	30.4	33.0	36.4	49.6	
20	D	6.5	7.5	8.8	12.1	9.5	10.6	11.6	12.1	13.0	14.7	20.4	
	V	23.4	23.5	25.3	31.3	23.8	24.6	24.6	23.8	23.6	24.2	24.7	

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C6

Travel Characteristics of the Routes of Zonal Combination 6

Percent Overlap	Route Number	1	2	3	4	5	6	7	8	9	10	11	12
0	T	15.0	16.2	19.0									
	D	6.8	11.3	7.8									
	V	27.1	41.7	24.6									
3	T	15.0	16.2	19.0									
	D	6.8	11.3	7.8									
	V	27.1	41.7	24.6									
5	T	15.0	16.2	19.0									
	D	6.8	11.3	7.8									
	V	27.1	41.7	24.6									
7	T	15.0	16.2	16.5									
	D	6.8	11.3	6.8									
	V	27.1	41.7	24.8									
10	T	15.0	16.2	16.5									
	D	6.8	11.3	6.8									
	V	27.1	41.7	24.8									
15	T	15.0	16.2	16.5	21.4	24.4							
	D	6.8	11.3	6.8	9.3	11.5							
	V	27.1	41.7	24.8	26.0	28.4							
20	T	15.0	16.2	16.5	17.9	18.0	20.9	23.7	25.1	30.4	32.9	39.2	40.5
	D	6.8	11.3	6.8	7.6	8.1	9.0	10.5	11.1	13.9	14.5	21.6	19.6
	V	27.1	41.7	24.8	25.5	27.1	25.9	26.5	26.6	27.4	26.4	33.0	29.0

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

TABLE C7

Travel Characteristics of the Routes of Zonal Combination 7

Percent Overlap	Route Number	1	2	3	4	5	6	7	8	9	10	11	12
0	T	24.2	29.5	30.9	33.8								
	D	9.2	11.9	21.2	13.3								
	V	22.8	24.2	41.2	23.6								
3	T	24.2	28.8	30.1	32.3	35.2	39.3	54.5					
	D	9.2	11.0	20.7	12.9	15.3	16.3	27.0					
	V	22.8	22.9	41.3	24.0	26.0	24.9	29.8					
5	T	24.2	28.8	30.1	31.4	32.3	39.3	54.5					
	D	9.2	11.0	20.7	12.7	13.9	16.3	27.0					
	V	22.8	22.9	41.3	24.3	25.9	24.9	29.8					
7	T	24.2	26.7	29.2	30.1	32.4	34.8	45.1	54.2				
	D	9.2	10.6	11.3	20.7	14.0	14.1	21.8	22.5				
	V	22.8	23.9	23.2	41.3	25.9	24.3	29.0	24.9				
10	T	24.2	26.5	28.5	29.5	30.0	30.1	32.4	34.8	43.9	52.7		
	D	9.2	10.0	11.4	11.4	11.8	20.7	14.0	14.1	18.0	26.4		
	V	22.8	22.7	24.0	23.1	23.7	41.3	25.9	24.3	24.7	30.0		
15	T	24.2	25.8	26.6	27.0	29.5	30.1	30.5	31.8	34.9	36.1	40.3	44.5
	D	9.2	9.9	10.6	10.3	11.6	20.7	12.1	12.1	14.2	14.4	15.7	18.4
	V	22.8	23.0	23.9	22.9	23.7	41.3	23.8	22.8	24.4	23.9	23.4	24.8
20	T	24.2	25.8	26.6	26.7	27.9	29.4	30.1	30.5	34.9	35.0	36.1	37.7
	D	9.2	9.9	10.6	9.9	10.6	11.6	20.7	12.1	14.2	13.4	14.4	15.3
	V	22.8	23.0	23.9	22.4	22.9	23.7	41.3	23.8	24.4	23.0	23.9	24.4

T = travel time (min)
D = total distance (mi)
V = overall speed (mph)

APPENDIX D
Monroe Trip Tables

TABLE D1

Monroe Trip Table - Internal Trips

Zone No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
01																									
02	28																								
03	46	20																							
04	30	19	18																						
05	45	14	6	6																					
06	35	15	17	15	12																				
07	60		25		12	31																			
08	72	24	70		12	28	28																		
09	90	21	46	13	15	38	10	63																	
10	73	37	33	16	11	24	33	48	42																
11	39	9	35	14	15	12		9	17	76															
12	60	26	15	13	24	12	25	33	37	25	6														
13	61	50	24	22	16		28	25	27	51	11	12													
14	104	23	41		26	36	18	22	51	52	19	36	66												
15	19	18	41	7	24	18	15	24	36	33	11	41	7	95											
16	40		11			6	29	18	14	32	17	12		9	22										
17	122	31	59		19	17	45	71	58	59	7	71	16	12	34	46									
18	32	12	10	14		19	6	11	22	25	10		35		60	10	36								
19	25	8	23		22	11	11	11	19	28			25	9	9	10	26	13							
20	15	18	16	6		7		17	6	40	15	19	16	16	6			12	7						
21	14								13	14						14			17	6					
22	37	24	31	9		20		25	20	73	22	8		13	26	15	25	14	18	12	14				
23	8		10					24		11	8	6	7	7		9			12			36			
24	43	16	13			12		17	17	61	9	47	34	18			12	6		15			7		
25	10		7	8		6	6		9	19					17		10	24	10			14		29	
	1108	413	617	210	279	391	382	652	684	916	361	528	533	67[illegible]	563	314	776	371	314	249	92	456	145	356	169

TABLE D2

Monroe Trip Table - Through Trips

Zone No.	26	27	28	29	30	31	32	33	34	35	36	37
26												
27	27											
28	47											
29	12											
30	661	28	10									
31	639	269	18		28							
32	10											
33	57	7										
34	59	32	17		24	10		6				
35	11	15	6		21	17		7				
36												
37		8			12	10		10	11			
	1523	386	98	12	784	991	10	87	159	77	0	51

APPENDIX D

Monroe Trip Tables

TABLE D3

Monroe Trip Table - External Internal Trips

Zone No.	26	27	28	29	30	31	32	33	34	35	36	37	
01	102	62	63		40	41	17	25	95	86	10	46	587
02	12	14	21		8	12		12	35	15		14	143
03	22	17	26		13	18		12	41	37		14	200
04	7												7
05	13												13
06	22	9			7	7		7	21	18		14	105
07	22	18	13		7	7		12	11	14		26	130
08	34	10	18		26	16		12	23	17		12	168
09	30	9	25		10	14		11	16	14		10	139
10	62	22	48	7	24	54	9	16	35	26		14	317
11	13					15			6				34
12	18		9					20	7				54
13	24								15			6	45
14	35		8		9			12	152			10	226
15	11				7				18	72		9	117
16	19	21	12		12	20			27	15	55	24	205
17	48	30	12		7	12		9	40	17	6	59	240
18	35	41	9		14	7		6	22	15		10	159
19	15	7						8	9				39
20	14	6	9		7	9			10				55
21			48										48
22	30	10	32	22	22	17	6	7	16	9		7	178
23	11		28		10	15			13	7			84
24	15				16	40							71
25	15	8	8		14	29			14				88
	629	284	389	29	253	333	32	169	626	362	71	275	

APPENDIX E

Monroe Link Table - Link Level of Service "C"

APPENDIX E

Monroe Link Table - Link Level of Service "C"

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
01	55	10	15	
01	56	10	15	
02	66	14	15	
02	67	14	15	
03	63	17	15	
03	68	13	15	
04	72	25	15	
04	78	25	15	
04	79	25	15	
05	75	15	20	
06	59	20	20	
07	47	12	20	
08	44	35	20	
08	49	35	20	
09	50	55	20	
09	52	35	20	
10	53	40	20	
10	70	47	20	
10	81	30	20	
11	73	27	20	
11	80	27	20	
12	86	45	25	
12	87	67	25	
13	86	55	25	
14	77	20	25	
15	57	25	25	
15	64	25	25	
16	38	60	25	
16	40	30	25	
17	38	38	25	
17	39	50	25	
18	39	50	25	
18	41	50	25	
19	45	50	25	
20	50	30	20	
20	53	20	20	
20	54	18	20	
21	45	70	25	

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
21	51	60	25	
22	51	35	25	
23	74	70	25	
23	85	35	25	
24	84	38	25	
24	87	53	25	
25	85	43	25	
25	88	36	25	
26	39	75	50	2050
27	39	83	40	500
27	41	89	40	500
28	45	110	40	500
29	51	73	40	500
30	85	60	40	500
31	88	26	40	500
32	87	54	40	500
33	86	28	40	500
34	77	46	40	500
35	57	25	40	500
36	40	42	40	500
37	38	77	40	500
38	16	60	25	
38	17	38	25	
38	37	77	40	500
38	42	55	40	500
39	17	50	25	
39	18	50	25	
39	26	75	40	2050
39	27	83	40	500
39	41	45	50	2050
39	43	46	35	500
40	16	30	25	
40	36	42	40	500
40	42	62	40	400
41	18	50	25	
41	27	89	40	500
41	39	35	50	2050
41	44	22	30	500
41	50	128	35	1200
42	38	55	40	500
42	40	62	40	400
42	43	28	30	300
42	46	35	30	500
43	39	46	35	500
43	42	28	30	300
43	44	22	30	300
43	47	52	30	500

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
44	08	35	20	
44	41	22	30	500
44	43	22	30	300
44	49	62	30	500
45	19	50	25	
45	21	70	25	
45	28	110	40	500
45	48	42	40	500
46	42	35	30	500
46	47	16	25	500
46	59	68	25	300
47	07	12	20	
47	43	52	30	500
47	46	16	25	500
47	55	41	20	500
48	45	42	40	500
48	50	43	30	150
48	54	42	30	300
49	08	35	20	
49	44	62	30	500
49	52	90	25	350
49	56	27	20	240
50	09	55	20	
50	20	30	20	
50	41	128	35	1200
50	48	43	30	500
50	52	41	30	500
50	53	25	35	1230
51	21	60	25	
51	22	35	25	
51	29	73	40	500
51	54	72	40	500
52	09	35	20	
52	49	90	25	350
52	50	41	30	140
52	53	44	30	300
52	70	24	25	500
53	10	40	20	
53	20	20	20	
53	50	25	35	1230
53	52	44	30	150
53	54	33	30	500
53	74	54	35	1230
54	20	18	20	
54	48	42	30	300
54	51	72	40	500
54	53	33	30	180

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
54	74	58	30	130
55	01	10	15	
55	47	41	20	560
55	56	13	20	400
55	60	10	20	560
56	01	10	15	
56	49	27	20	500
56	55	13	20	400
56	61	11	20	200
56	63	26	20	400
57	15	25	25	
57	35	25	40	500
57	58	42	40	500
58	57	25	40	500
58	59	42	30	500
58	64	20	30	300
59	06	20	20	
59	46	68	25	300
59	58	42	30	500
59	60	42	25	480
59	65	9	25	300
60	55	10	20	800
60	59	42	25	550
60	61	11	20	400
60	66	8	20	500
61	56	11	20	400
61	62	11	20	650
61	62	8	20	400
61	67	8	20	300
62	61	8	20	480
62	63	12	20	440
62	68	8	20	400
63	03	17	15	
63	56	26	20	500
63	62	12	20	640
63	69	15	20	500
64	15	25	25	
64	58	20	30	300
64	76	64	30	300
65	59	9	25	300
65	66	42	25	320
65	75	44	25	300
66	02	14	15	
66	60	8	20	800
66	65	42	25	300
66	67	10	20	400
66	71	18	20	500
67	02	14	15	

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
67	61	8	20	200
67	66	10	20	230
67	68	8	20	400
67	72	18	20	400
68	03	13	15	
68	62	8	20	400
68	67	8	20	440
68	69	25	20	400
68	79	65	25	400
69	63	15	20	500
69	68	25	20	450
69	70	33	25	300
69	73	41	25	400
70	10	47	20	
70	52	24	25	500
70	69	33	25	300
70	73	22	25	300
71	66	18	20	800
71	72	9	20	400
71	75	50	25	500
72	04	25	15	
72	67	18	20	350
72	71	9	20	400
72	78	50	25	500
73	11	27	20	
73	69	41	25	500
73	70	22	25	500
73	81	32	30	400
74	23	70	25	
74	53	54	35	1230
74	54	58	30	300
74	82	40	30	1 30
74	84	58	35	1230
75	05	15	20	
75	65	44	25	300
75	71	50	25	500
75	76	30	30	500
76	64	64	30	300
76	75	30	30	500
76	77	41	35	500
77	14	20	25	
77	34	46	40	500
77	76	41	35	500
78	04	25	15	
78	72	50	25	500
78	79	11	30	400
78	86	50	35	400

N(I)	J(I)	DLINK(I)	VLINK(I)	ICAP(I)
79	04	25	15	
79	68	65	25	400
79	78	11	30	400
79	80	43	30	300
80	11	27	20	
80	79	43	30	400
80	87	70	30	300
81	10	30	20	
81	7[illegible]	32	30	500
81	82	34	30	400
81	87	55	30	400
82	74	40	30	400
82	81	34	30	500
82	83	22	30	400
83	82	22	30	500
83	84	40	30	150
83	87	41	30	400
84	24	38	25	
84	74	58	35	1200
84	83	40	30	500
84	85	58	40	500
84	88	76	40	500
85	23	35	25	
85	25	43	25	
85	30	60	40	500
85	84	58	40	500
86	12	45	25	
86	1[illegible]	55	25	
86	[illegible]	28	40	500
86	78	50	35	500
87	12	67	25	
87	24	53	25	
87	32	54	40	500
87	80	70	30	400
87	81	55	30	300
87	83	41	30	300
88	25	36	25	
88	31	26	40	500
88	84	76	40	500

NLINK = 266

NZONE = 88